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RAYMOND C. MOORE
EDITOR

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THE BULLETIN

of the

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RAYMOND C. MOORE, *Editor*

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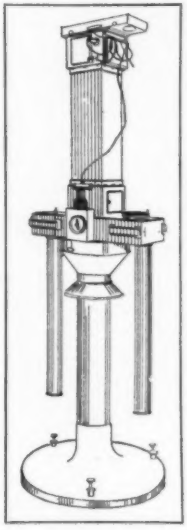

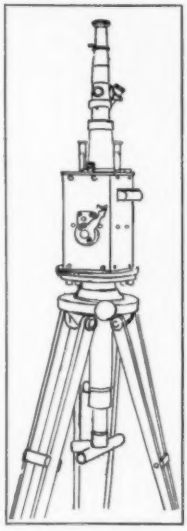

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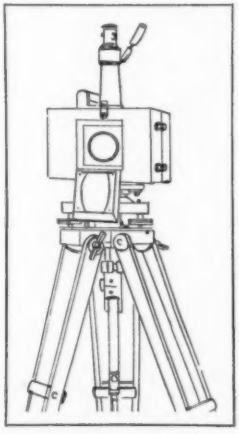

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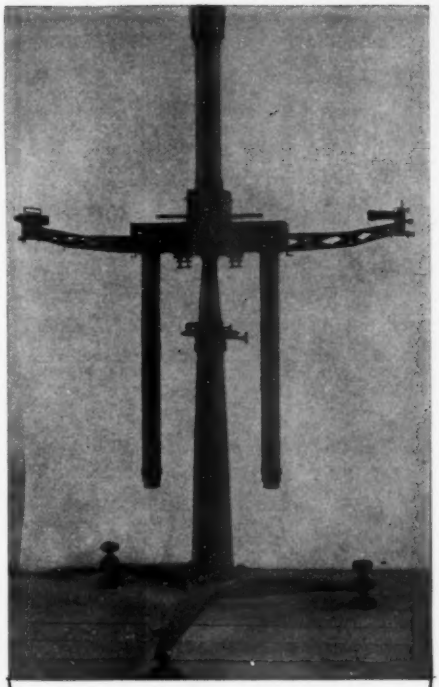

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MARCH 1926

EARLY PENNSYLVANIAN DEPOSITS WEST OF THE NEMAHA GRANITE RIDGE, KANSAS

RAYMOND C. MOORE
University of Kansas, Lawrence, Kansas

ABSTRACT

Several deep wells west of the granite ridge in east-central Kansas have penetrated red beds and a thick chert zone near the base of the Pennsylvanian section. Study of the materials indicates that the chert, red clay, and other débris are derived from deeply weathered rocks along the granite ridge. Since these coarse deposits overlie fine clay shale of early Pennsylvanian age, it appears that a moderately strong uplift of the ridge occurred in early Pennsylvanian, perhaps late Cherokee time—long after the first uplift of the ridge.

INTRODUCTION

In connection with studies of the buried Nemaha Granite Ridge in east-central Kansas which from time to time the writer has carried forward, attention has been directed to the lithologic and stratigraphic characters of the sedimentary rocks adjacent to the ridge. It is now well known that above or adjacent to different parts of the ridge the Pennsylvanian beds rest unconformably on Mississippian, Ordovician, or pre-Cambrian crystalline rocks. It is also established that where the ridge is highest the lower Pennsylvanian beds cover only the flanks of the uplifted older rock mass, that the higher Pennsylvanian strata progressively overlap upon the ridge, and that in northern Kansas the youngest formation of Pennsylvanian age, the Wabaunsee, rests directly on granite. This paper calls attention to certain characteristics of the lower Pennsylvanian deposits in the area west of the granite ridge in central Kansas and discusses briefly the problem of their correlation and historical interpretation.

THE SECTION IN SOUTHERN MARION AND EASTERN HARVEY COUNTIES

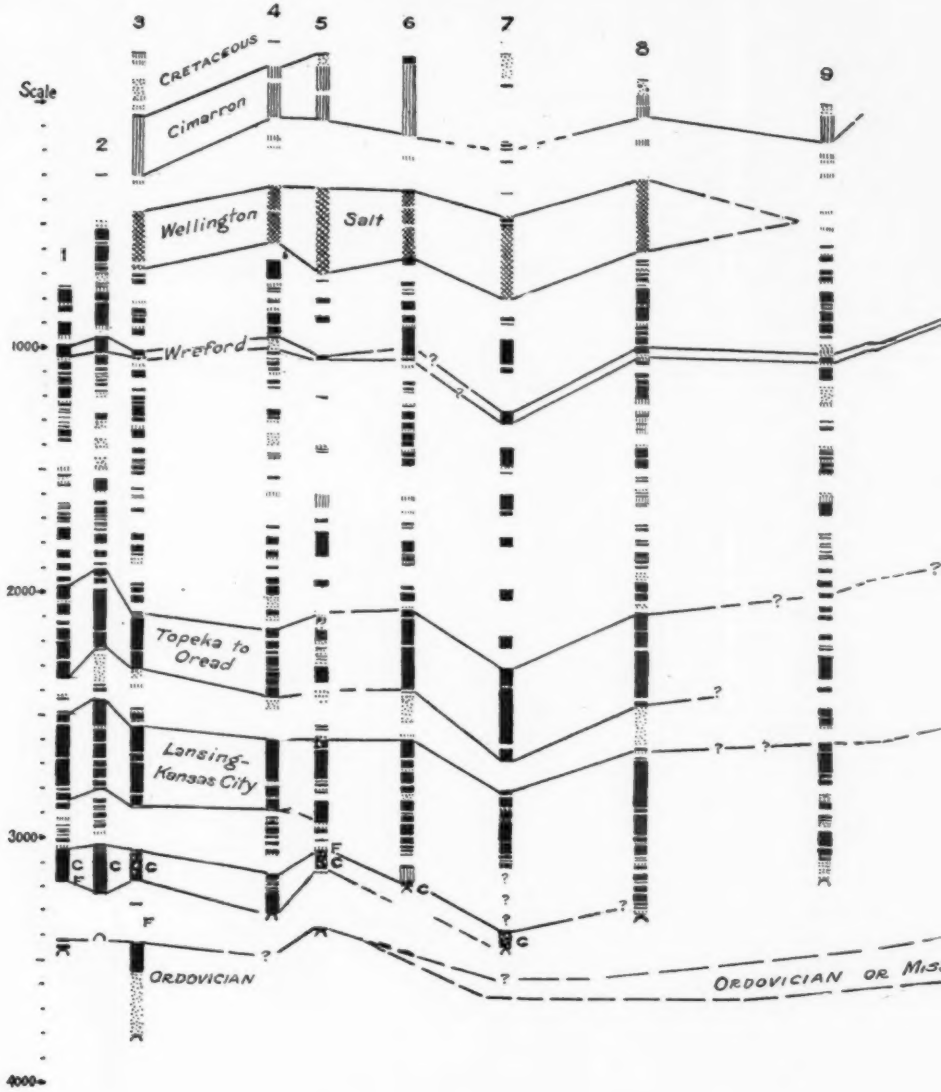
In the Florence, Peabody, and adjacent oil-producing districts of southern Marion County, wells begin in the lower part of the marine Permian which consists of alternating shale and thin limestone. In the logs and cuttings one horizon, the Wreford chert, occurring not far below the surface, can generally be recognized by its cherty, fossiliferous character and other features. The upper part of the Pennsylvanian consists largely of shale with many thin beds of limestone. This includes all of the Wabaunsee and part of the upper Shawnee formation, as defined at the outcrop. Beneath this are two dominantly limestone zones each 300–400 feet thick, separated by 150–300 feet of shaly strata. The upper limestone zone is correlated with the limestones Oread to Topeka and includes, therefore, the lower part of the Shawnee and the uppermost member of the Douglas formation. The lower limestone zone appears to correspond to the Lansing and Kansas City formations. The intervening shale thus represents the part of the Douglas formation below the Oread limestone. The lower part of the Pennsylvanian in southern Marion County consists mainly of shale, about 350 feet in average thickness. There are intercalated beds of limestone, sandstone, red rock, and in some cases cherty gravel. Presumably this lower part represents the Marmaton and more or less of the Cherokee of southeastern Kansas.

As indicated by the character of the contained water, and by examination of the cuttings in several wells, the rocks beneath the Pennsylvanian are classified as Ordovician; they consist of cherty dolomite or dolomitic limestone. Typical south Marion County logs are shown in Plate 11, Nos. 16, 17, 20–25.

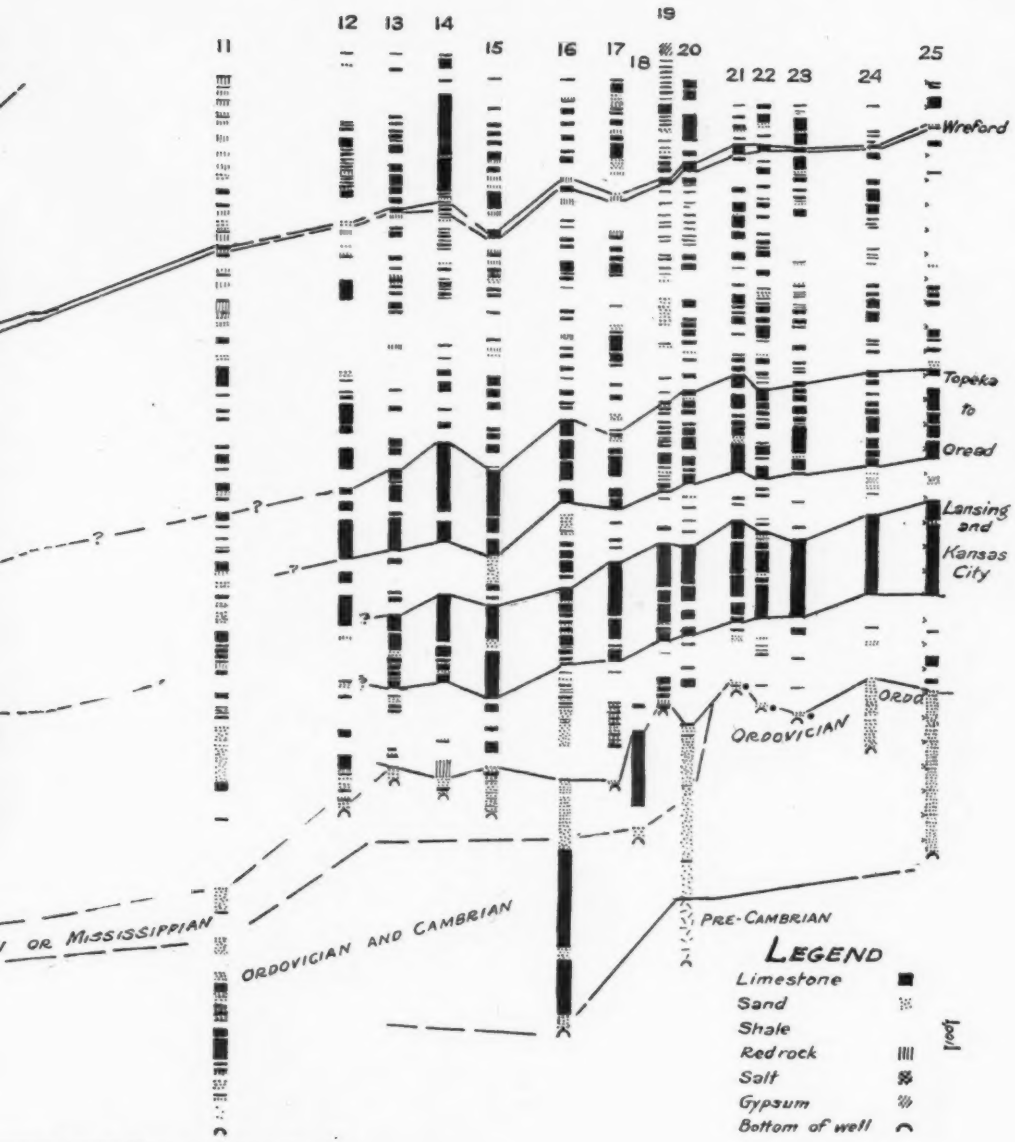
In eastern Harvey County, which adjoins the Peabody-Florence district on the southwest, subsurface conditions are essentially unchanged (wells 12–15, 18, 19, Plate 11) except that in some or perhaps most of the wells, Mississippian rocks next underlie the Pennsylvanian.

THE SECTION IN RENO, RICE, AND ELLSWORTH COUNTIES

In the course of wildcat drilling in Reno, Rice, and Ellsworth counties, approximately 60 miles west of the Peabody-Florence fields, interesting information on subsurface conditions has been ob-



CORRELATED WELL SECTION ACRO
(C—Chert. F-



ECTION ACROSS PART OF CENTRAL KANSAS
(C—Chert. F—Fossils.)

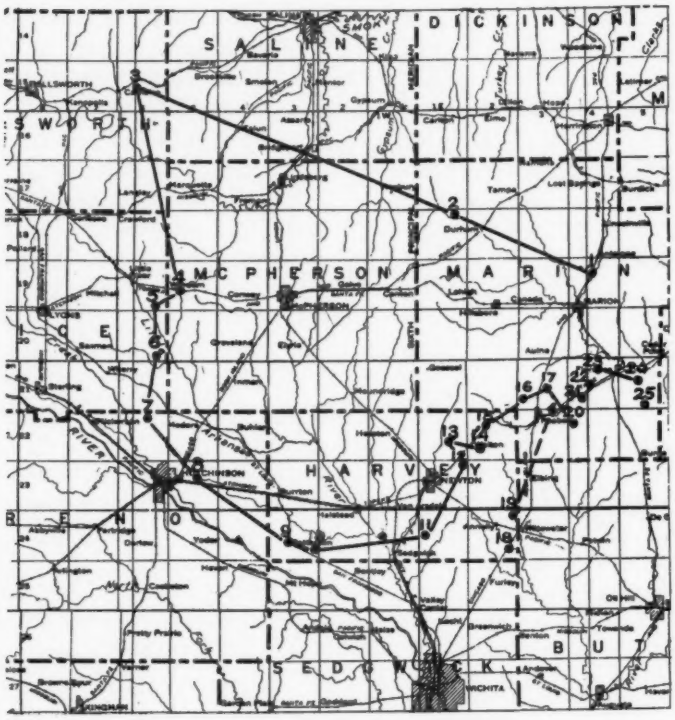


FIG. 1.—Index map showing location of wells represented in Plate 11

LIST OF WELLS

	Location	Depth
1. Batt	9-19-4E.	(2,700)
2. Clark (Mountain States)	2-18-1W.	(3,094)
3. Sheridan (Keys)	21-15-6W.	(4,007)
4. King (Ladow)	20-19-5W.	(3,555)
5. Deeds-Day (Rhino)	35-19-6W.	(3,570)
6. Welch (Hipple-Childs)	35-20-6W.	(3,380?)
7. Sallee	3-22-6W.	(3,750?)
8. ———	10-23-5W.	(3,400)
9. Crosby (Waldo)	21-24-3W.	(3,165)
10. Wilkerson	25-24-3W.	(2,771)
11. Kirkpatrick (Humphrey)	20-24-1E.	(4,300)
12. King (Watchorn)	1-23-1E.	(3,065)
13. Parkhurst (Blazler)	22-22-1E.	(2,960)
14. Wilson (Houston)	28-22-2E.	(3,018)
15. Guthrie	9-22-2E.	(3,008)
16. Symons (Elmhurst)	29-21-3E.	(3,870)
17. Hudson (Stober)	22-21-3E.	(2,870)
18. ———	26-24-2E.	(3,322)
19. Monarch	1-24-2E.	(2,765)
20. Milne (Watchorn)	7-22-4E.	(3,615)
21. Stovall (National)	28-21-4E.	(2,380)
22. Miller (Ramsey)	21-21-4E.	(2,455)
23. Hildreth (Gypsy)	10-21-4E.	(2,485)
24. Urschel 4	16-21-5E.	(2,620)
25. Davis (Ohio cities)	34-21-5E.	(3,155)

tained (wells 3–8, Plate 11). Some of the wells start in the Dakota sandstone; all pass through the lowermost part of the Cimarron red beds and the thick salt horizon which belongs in the Wellington shale. Where cuttings are available for microscopic study the Wreford has been identified, but elsewhere its recognition is not certain. In the lower part of the wells are two prominent limestone divisions corresponding evidently to the lime zones observed in southern Marion and eastern Harvey counties and correlated with the Topeka-Oread and Lansing–Kansas City, respectively. Except perhaps in the Sheridan well, eastern Ellsworth County (well 3, Plate 11), there is, however, no very definite lower boundary in the case of the Lansing–Kansas City limestone. Beneath the thick limestones that seem clearly assignable to the Lansing–Kansas City of areas farther east are found thin alternating limestones, sand, red beds, and thin shale beds.

In each of the described wells from Reno, Rice, and Ellsworth counties there is encountered a zone consisting mostly of white chert, and ranging in thickness to nearly 200 feet. A part of the chert is much weathered, rotten, and is deeply stained by iron oxide; there are rounded and unevenly pitted surfaces that contrast strongly with fresh broken surfaces made by the drill. Very much of the chert has been broken up by the drill and is correspondingly sharp angled and splintery; it consists in large part of very dense "butcher knife" chert, and much of it is not unlike the "chat" so widely used as road metal in the Joplin country and elsewhere. In some cases the cuttings consist of almost nothing but this chert for scores of feet, and the horizon is naturally very distinctive. Some of the samples show more or less admixed red clay, and not uncommonly there are a few fairly large, very well-rounded, and often frosted grains of transparent quartz. Irregular fragments of fine sandstone or in some cases more or less siliceous and dolomitic limestone occur also. Fragmentary, worn, silicified fossils, some of them apparently derived from the Mississippian, appear to be secondarily deposited in this formation. In one case the only basis for recognition of a crinoid stem collected from cuttings at this horizon was the cylindrical shape and the preservation of the small, jaggedly, sawlike sutures between the individual stem segments. After silicification the stem had been ex-

posed to prolonged weathering and very much of the silica had in turn been replaced by hematite.

The red material associated with the chert occurs below it, above it, or intermingled with it. Microscopic examination shows that the red rock is mostly a very deeply oxidized, ferruginous, clayey material like the residual, strongly ferruginous clay that is seen in most limestone regions. A part of the red material is a typical geest with abundant scattered sand grains and other foreign material in a matrix of red clay. Indeed, the entire deposit suggests strongly the residual chert and red clayey materials which are so common in the Mississippian areas of southwest Missouri and other parts of the country.

In the upper part of this cherty zone oil has been found, and at least in the case of the Welch well (No. 6, Plate 11) in Sec. 35, T. 20 S., R. 6 W., the quantity of production was regarded as sufficient for commercial operation.

Beneath the well-defined chert zone which has been described is a persistent shale which, as indicated by at least three widely scattered wells in this area that have passed through it, has a thickness of a little more than 200 feet. As shown by drill cuttings, this shale is a very uniform fine-grained, light bluish-gray clay shale. For the most part, search for fossils in the shale cuttings has been unsuccessful, but in the middle part of this shale in the Sheridan well (No. 3, Plate 11) in Sec. 15, T. 15 S., R. 6 W., Ellsworth County, there are abundant fossils consisting mostly of the broken shells of *Derbya crassa*. Two complete specimens of this species were brought up in the bailer from this horizon, and were referred to the writer for identification at the time the well was being drilled. *Fusulina* is also found. Since fragments of these fossils occur in the drill samples above the horizon where they are most abundant, it seems that the occurrence indicates definitely the Pennsylvanian age of this shale. The fossils are not plausibly explained as the result of a cave.[1] A less

[1] The writer's attention has recently been called to the fact that 6⅝-inch casing was run in this well to 3,300 feet, well below the top of the chert which was reached at 3,270 feet. This precludes the possibility of shale caves from above the chert. Since the abundant and excellently preserved fossils from about 3,500 feet admit no question as to Pennsylvanian age the chert and at least the upper part of the shale beneath it are assigned with definiteness to the Pennsylvanian.

diagnostic collection of fossils, also indicating Pennsylvanian age, was secured in the bottom of the chat zone in the Batt well (No. 1, Plate 11), east-central Marion County.

If this shale is Pennsylvanian, its lithologic character and stratigraphic relations are of special interest. The fine, non-red clay and very uniform texture indicate very quiet deposition. It seems very unlikely that there could have existed anywhere near by an uplifted land mass, the active erosion of which should contribute to adjacent deposits a character differing more or less strongly from this shale. The Nemaha Ridge had been elevated, however, before the time this shale began to be deposited, since, as will be noted, the shale rests unconformably on Ordovician rocks. It seems, therefore, that before the initiation of Pennsylvanian sedimentation in this region the land that had appeared in middle or late Mississippian time and at least the nearby part of the Nemaha Ridge, whose appearance probably coincides approximately with the withdrawal of the Mississippian sea, had been reduced to a very low relief (Fig. 2).

Referring again to the chert above the shale, it must be concluded that this deposit is not a deeply weathered part of the Mississippian limestone with residual red clay *in situ*. It is a deposit of Pennsylvanian age that apparently was formed by removal of the products of weathering in adjacent territory of cherty older rocks. This is indicated, in the writer's opinion, by the evidences of weathering of the chert, the admixture of various other sorts of rock material with the chert, the occurrence of secondary fossils, and the association with red-clay geest. The deposit is then very different from the ordinary cherty limestone in which the chert is endogenous. The source of the chert is most probably the Mississippian and Ordovician rocks that formerly covered the Nemaha Granite Ridge. If this interpretation is correct, the formation is certainly not to be correlated with any of the recognized stratigraphic subdivisions of the Cherokee-Marmaton portion of the Pennsylvanian section in southeastern Kansas. Since the deposit is a very readily recognizable and fairly widespread unit that yields oil in various places, it seems desirable to give to it a name. Since the chert is best developed in the western area here described and was first widely known on account of production obtained in it from the Welch well in Sec. 35, T. 20 S.,

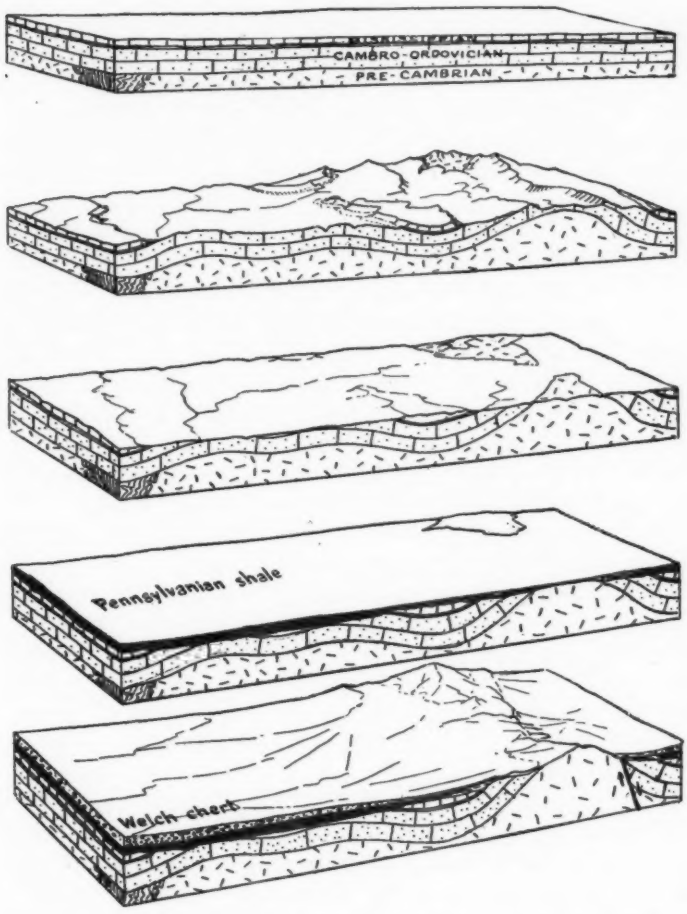


FIG. 2.—Diagrams representing successive stages in inferred history of a part of the Nemaha Granite Ridge, east-central Kansas. 1, Cambro-Ordovician and Mississippian deposits laid down over site of ridge; 2, late-Mississippian or early Pennsylvanian orogeny—removal by erosion of parts of the Mississippian, Ordovician, and (?) Crystalline rocks; 3, erosion continued until relief very weak; 4, invasion of Pennsylvanian sea —deposition of fine-grained clay shale; 5, renewed uplift, producing rough topography and accentuating relief along Nemaha Ridge and causing deposition of Welch chert.

R. 6 W., Rice County, the name "Welch chert" is suggested. If evidences of the clastic character of the deposit are substantiated it may be desirable to use the designation "Welch chert gravel." Near parts of the granite-ridge pebbles of crystalline rocks may become common or event dominant. Such pebbles have been obtained at approximately the Welch horizon both east and west of the crest of the ridge.

It should be noted that there are doubtless several horizons or zones of gravelly material in the Pennsylvanian near the Nemaha Ridge. The Welch chert may not be traceable definitely to a specific gravel near the ridge, although Ainsworth[1] and others report a distinctive chert and red-rock zone at the approximate horizon of the Welch in parts of Butler, Marion, and other counties. In some places such material rests directly on massive pre-Pennsylvanian rocks. The prominence of the Welch chert and the wide spreading of deeply oxidized ferruginous clays and other weathering products suggests a moderately strong uplift of the Nemaha Ridge at this time.

The rocks underlying the shale zone in the Reno, Rice, and Ellsworth county wells are dolomite and contain more or less chert. In the Sheridan well (No. 3, Plate 11) this hard dolomitic and sandy zone, which on the basis of study of the cuttings appears fairly definitely referable to the Ordovician, was penetrated for more than 350 feet. Cuttings at this horizon from the Deeds-Day well (No. 5, Plate 11) show similar materials beneath the shale.

As shown in Plate 11, the Sheridan and other western wells may be correlated very readily with wells in northern and east-central Marion counties (Nos. 1, 2, Plate 11), in which the very typical Welch chert material and the underlying light shale are found. The latter is underlaid in the case of the Batt well (No. 1, Plate 11) by siliceous dolomite which belongs apparently to the Ordovician.

Wells in southern Harvey County show either very different conditions in the lower part of the Pennsylvanian or the logs are very poor. No satisfactory correlation has been made by the writer.

THE KINGMAN COUNTY SECTION

Since the foregoing discussion was written, the Fleeger well in Sec. 16, T. 27 S., R. 7 W., Kingman County, has been drilled into

[1] W. L. Ainsworth, personal communication.

oil and has attracted widespread interest to this region. Brief reference to subsurface conditions here discovered is introduced in the proof.

Kingman County, adjoining Reno on the south, lies a few miles west of Wichita. The area is covered by Permian red beds and thin remnants of Tertiary; key beds which may be used for surface structure mapping are almost entirely wanting. The Wellington salt, dipping gently westward, occurs about 800 to 1,000 feet below the surface and has a thickness of more than 300 feet. The underlying Permian and Pennsylvanian limestone, shale, sandstone, and thin "red rock" formations are similar to those which are found farther north and may be correlated readily with general divisions shown in Plate 11. The oil-producing zone in the Kingman County well mentioned consists largely of chert which by a majority of geologists is regarded as the cherty top of the "Mississippi lime," but by some geologists is variously correlated with formations ranging from the "Oswego lime" (Fort Scott) to the Ordovician. The writer has received a communication from W. L. Ainsworth stating that study of a north-south cross-section which he has constructed from the Sheridan well in Ellsworth County through Rice, Reno, and Kingman counties, using in part wells here shown (Plate 11), indicates with very small doubt that the cherty oil-producing formation in Kingman County is the same as the cherty oil-producing formation in Rice County, here called the Welch chert. If this conclusion is correct, the Pennsylvanian age of the chert and probably of the underlying dark shale in the Kingman area cannot be doubted.[1]

In the Bane well, NW. sec. 22, T. 29 S., R. 8 W., Ainsworth reports that examination of the cuttings of the siliceous limestone reported from 4,188 to 4,375 feet, consists almost entirely of chert. This appears to represent the Welch chert. It is possible, but not certain, that the underlying shale in this place is Pennsylvanian.

CONCLUSIONS

A review of the evidence contained in the well records and secured from the examination of cuttings appears to afford basis for the following conclusions.

[1] Micro-fossils from the producing horizon in the Fleeger well, subsequently shown the writer through the Courtesy of Dr. Sidney Powers, indicate the Ordovician age.

1. Mississippian and Ordovician rocks formerly extended across the site of the Nemaha Ridge and probably covered all of this region. Typical sections of the Mississippian represented by complete sets of cuttings have been studied by the writer in north Sumner County west of the ridge and are reported by Ley[1] in southeast Harvey County (see No. 18, Plate 11), and by W. L. Ainsworth[2] in Sedgwick, west Butler, and Saline counties. Where the Mississippian is recognized a varying thickness of black shale, apparently referable to the Chattanooga, and in some cases sand (Sylamore) is found. Ordovician rocks next underlie the Pennsylvanian in many places.

2. Pre-Pennsylvanian erosion not only beveled and entirely eroded the Mississippian strata in places, but carved to varying depths into the subjacent Ordovician. All of the Paleozoic strata and an unknown thickness of the pre-Cambrian crystalline rocks were removed along parts of the ridge. Locally, black shale belonging to the Chattanooga may immediately underlie shale of Pennsylvanian age.

3. The shale which rests unconformably on the Ordovician and in places on the Mississippian surface is assigned to the Pennsylvanian on the basis of its contained fossils. Judging from its fine uniform texture and non-red color, the adjacent Nemaha Ridge area which presumably had been uplifted and subjected to prolonged erosion in late Mississippian and early Pennsylvanian time must have been so reduced that little material from this source was contributed to the adjoining areas where this shale spread. The shale probably corresponds to some part of the Cherokee but there is no present basis for conclusion that the shale of this area corresponds to the entire Cherokee of southeastern Kansas or to some given part of that section.

4. The Welch chert zone is evidently a secondary deposit, the Mississippian and Ordovician rocks being probably the source of the cherty débris, secondary fossils, and admixed red and other clastic materials. The thickness and the very striking predominance of chert as shown in some of the cuttings is surprising, though the latter is possibly explainable in part by loss of fine materials in washing the samples. The chert is widely distributed in Marion, McPherson,

[1] Henry A. Ley, this *Bulletin*.

[2] Through personal communication.

Reno, Rice, Ellsworth, and probably adjoining counties. Locally the cherty débris is productive of oil. The deposit strongly suggests an important uplift of the Nemaha Ridge area which brought about vigorous erosion and the spreading of the products of earlier rock decay along the ridge to the country on the west and probably also to that on the east. In the area east of the ridge, red strata occur at about the same horizon above the base of the Pennsylvanian, associated with lenticular sands which are clearly derived from the ridge.

5. The Welch chert does not correspond to the more or less cherty dolomitic limestone which is productive in the Florence-Peabody district (see Plate 11). Similarly, it is probably not the same as the Stapleton pay in the El Dorado field though it is very probable that cherty zones in the immediate vicinity of the granite ridge correspond to the Welch and may in some cases be indistinguishable from the Stapleton, especially if the "chat" zone comes to rest immediately on the underlying massive hard Mississippian-Ordovician strata.

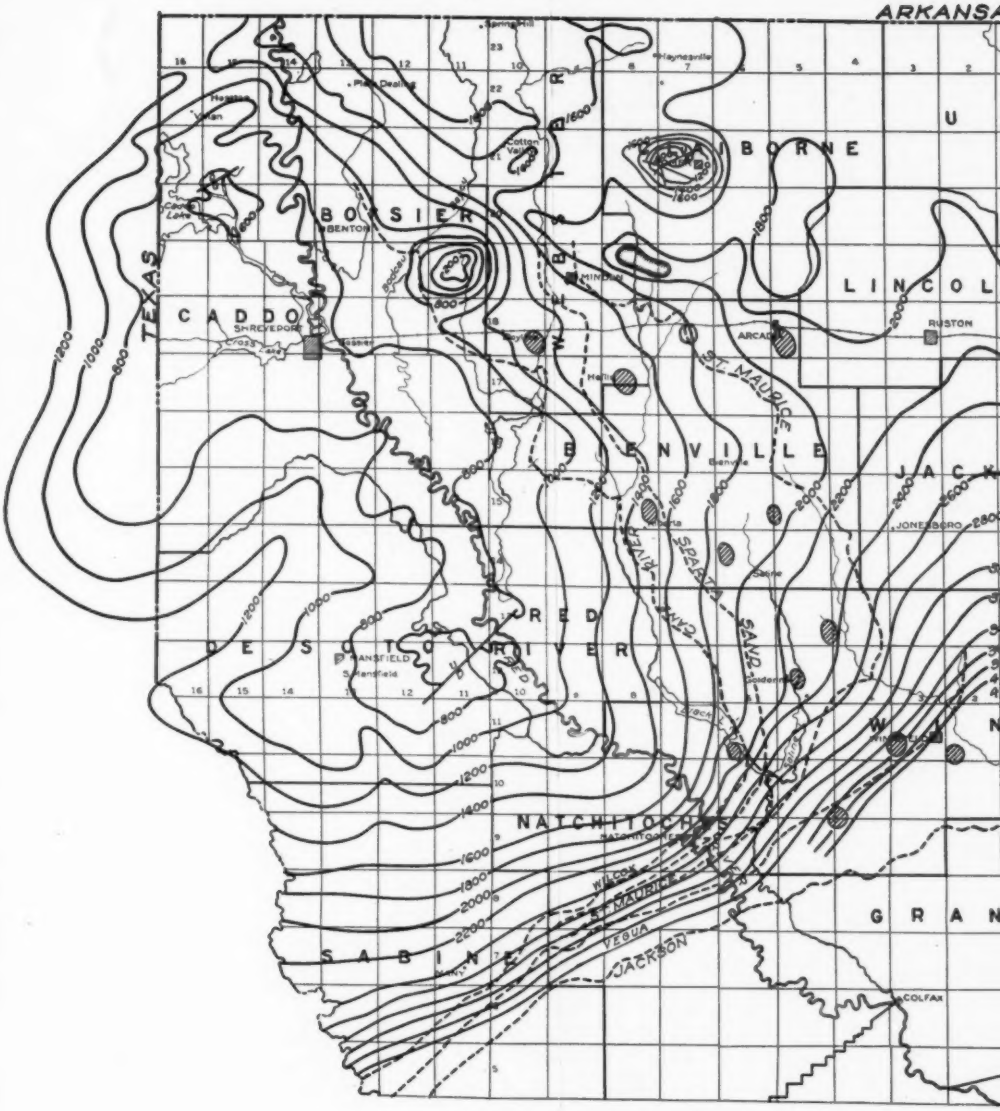
6. If the beds below the Welch chert should be referable to the Cherokee and those above to the Marmaton, the chert zone has the stratigraphic position of the Fort Scott ("Oswego") limestone. The writer believes, however, that there is no basis for this correlation, and, indeed, that the very different character of the Pennsylvanian deposits near the Nemaha Ridge and at a great distance from the outcrop makes any correlation of the smaller stratigraphic units of the standard section with distant subsurface divisions very unreliable. Since the Welch chert is probably a clastic deposit, and is very different in lithologic character and thickness from the Fort Scott limestone of eastern Kansas, it should certainly not be designated as Fort Scott.

7. If the conditions which have been described in this region are correctly interpreted, there was prolonged erosion and possibly a near obliteration of the topographic irregularities of the Nemaha Ridge prior to the beginning of the Pennsylvanian sedimentation in this region. In the latter part of Cherokee time, it appears, there was a pronounced uplift along the ridge which renewed topographic irregularities, caused extensive erosion and the transfer of chert and

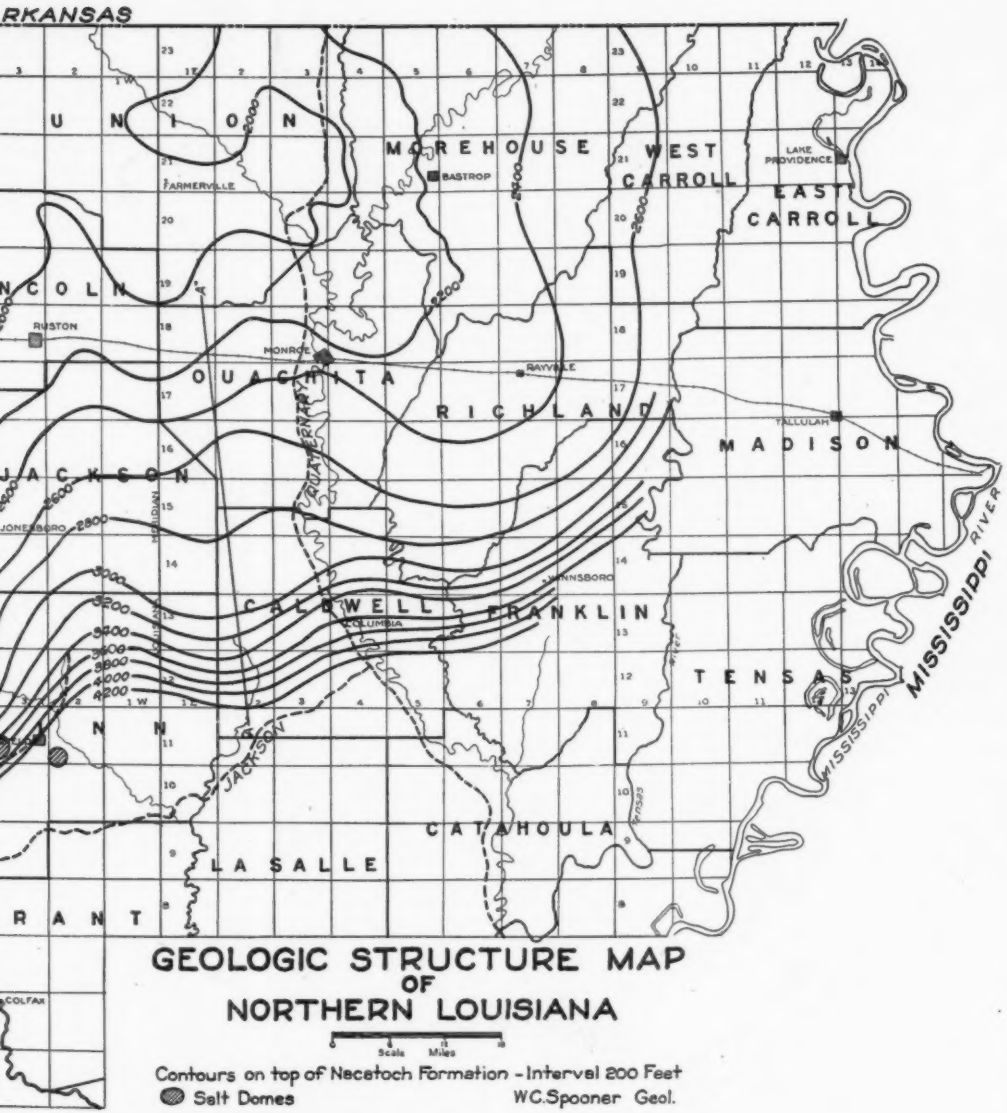
other débris including much red material to the districts west and east. It is particularly in connection with the gravel and sand bodies thus strewn out in the lower Pennsylvanian series in adjoining areas that much of the oil production of these districts comes. Whether or not the areas of Cherokee shale deposition to the east and west of the ridge were exposed for a time to erosion and consequently whether there is a recognizable, perhaps widespread unconformity in the Pennsylvanian sediments at this horizon is not definitely known. The occurrence of shallow channels and elongate sand bodies at approximately this horizon in eastern Kansas, as described by Rich,[1] Berger,[2] and others, is suggestive.

[1] This *Bulletin*, Vol. 7 (1923), p. 103.

[2] *Ibid.* Vol. 31 (1919), p. 212.



GEOLOGIC STRUCTURE MAP OF LOUISIANA, SHOWING TH



GEOLOGIC STRUCTURE MAP OF NORTHERN LOUISIANA

Scale 0 5 10 Miles

Contours on top of Nacatoch Formation - Interval 200 Feet

Salt Domes

W.C. Spooner Geol.

SHOWING THE STRUCTURE OF THE NACATOCH FORMATION

INTERIOR SALT DOMES OF LOUISIANA

W. C. SPOONER
Shreveport, Louisiana

ABSTRACT

The eleven known interior salt domes of Louisiana, herein described, are distinct and separate from the Gulf Coast domes. They occur in an area of Claiborne Eocene exposures, on the east flank of the Sabine uplift, in the northwestern part of the state. They are distinguished from the common salines by characteristic salt-dome topography and other surface manifestations.

This paper lists the more important publications on the Louisiana interior domes, dating from Forshey, in 1850, to Harris, in 1910, and adds thereto much new information secured by recent drilling and by special investigations of the author and others.

All but one of these domes have been partially explored by drilling for oil and gas, but as yet no production has been found. The history, topography, and geology of each dome are described in detail.

INTRODUCTION

LOCATION OF SALT DOMES

The salt domes of Louisiana, based on the geographic distribution, are divided into interior and coastal domes. The coastal domes occur in a belt about 70 miles wide, bordering the Gulf of Mexico. The known interior domes, separated from the coastal domes by a district apparently lacking salt domes, are limited to a rectangular area on the east flank of the Sabine uplift, about 75 miles long and 35 miles wide, which includes most of Bienville and Winn parishes. The longest dimension of the rectangle extends from southern Winn Parish to the Vicksburg, Shreveport & Pacific Railroad in southern Webster Parish, and is parallel to the axis of the Sabine uplift.

Bistineau salt dome, in southern Webster Parish, is located in the northwest corner of the rectangle; Vacherie dome is on the line of Webster and Bienville parishes; Arcadia, Rayburn's, King's, and Prothro domes are in Bienville Parish; Coochie Brake, Cedar Creek, Winnfield Quarry, and Price's domes are in Winn Parish; and Drake's dome is on the line of Winn and Natchitoches parishes. The locations of the salt domes are shown in Figure 1 and Plate 12.

The Sikes dome, in northwestern Winn Parish, is probably a salt dome, although neither cap rock nor salt has been found. A well

now being drilled in Sec. 15, T. 18 N., R. 7 W., Webster Parish, found the Upper Cretaceous at a depth of 570 feet, the top of the Lower Cretaceous probably at 978 feet, and anhydrite at 1,169 feet, indicating beyond reasonable doubt that it is on a typical salt dome.

SALINES

In addition to the salt domes described here, there are several localities which may, on further exploration, prove to be typical

FIG. 1.—Index map of northern Louisiana and southern Arkansas showing locations of salt domes and oil and gas fields.

salt-dome structures. These localities, commonly known as "salt licks," or "salines," are usually barren, or nearly barren, spots where salt waters reach the surface from shallow depths. Sulphur water is found associated with the salines in some places. Characteristic salt-dome topography, steeply dipping beds, and outcrops of rock older than those usually found at the surface have not been recognized in these localities. The better known and most characteristic of the salines are listed:

Bayou Castor Saline, in southeastern Winn Parish, about 3 miles

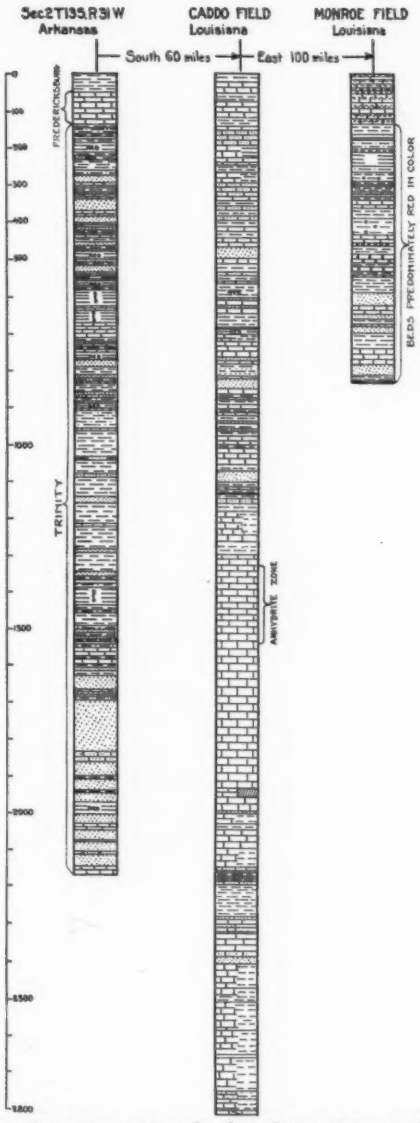


FIG. 2.—Lower Cretaceous sections showing relation of these beds in southwestern Arkansas, northwestern and northeastern Louisiana.

north of Rochelle; the salines cover portions of Secs. 15, 16, 21, and 22, T. 10 N., R. 1 E.

Brown's Saline, in southeastern Winn Parish, 18 miles southeast of Winnfield and 3 miles northwest of Rochelle, in Sec. 30, T. 10 N., R. 1 E.

Salt Springs, in southeastern Red River Parish, along Grand Bayou, in Sec. 22, T. 12 N., R. 8 W.; open saline with springs of weak brine and springs flowing sulphur water.

Clear Lake, in T. 11 N., R. 6 W.; salt and sulphur water in spring; gas emanations.

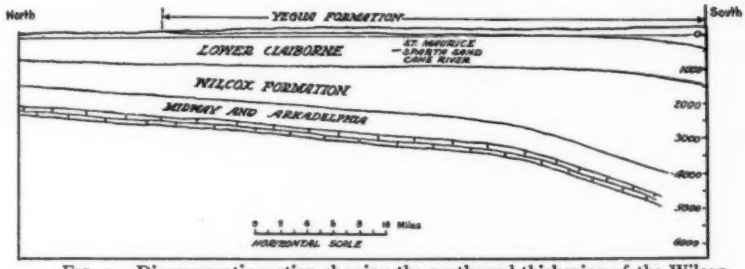


FIG. 3.—Diagrammatic section showing the southward thickening of the Wilcox formation.

SOURCES AND ACKNOWLEDGMENTS

Many references to the salt springs of northern Louisiana are found in the published accounts of the early travelers and explorers of this region. A very complete list of references is given by Veatch[1] and DeGolyer.[2] The first notable contribution to the knowledge of the geology of northern Louisiana was by Hilgard[3] in 1869 and 1873. The later publication contains the more detailed statement of the geology and the salines. Other investigators of this period were Hopkins, Lerch, and Vaughan.[4]

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 49–50.

[2] E. DeGolyer, "Origin of North American Salt Domes," *Bull. Am. Assoc. Petroleum Geologists*, Vol. 9, No. 5 (August, 1925), pp. 831–74.

[3] E. W. Hilgard, "Summary Result of a Late Reconnaissance of Louisiana," *American Journal of Science*, 2d Ser., Vol. 47 (1869), pp. 78–88; *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans, 1873.

[4] See literature.

The most important period of investigation began in 1889 and continued to 1910. During this period G. D. Harris and A. C. Veatch, of the Geological Survey of Louisiana, mapped and described the geology of Louisiana. *The Salines of North Louisiana*, by A. C. Veatch, published in 1902, contains a very detailed and complete description of the then known salt domes of this region. The numerous publications by these authors are referred to elsewhere or listed in the bibliography.

In preparation of this paper the writer has spent considerable time in field work, mapping the topography and geology of the several salt domes with telescopic alidade and plane-table. He has collected and carefully examined all available data, such as well records, cores, and cuttings, and has used freely previous publications, for which credit is given in the proper places.

It is a pleasure to acknowledge the whole-hearted co-operation of the geologists of this region, who have generously furnished information, assistance in mapping, and valuable suggestions, and it is a regret that lack of space prohibits acknowledgment to each individual. The companies have been equally generous in furnishing available information. The writer is especially indebted to Francis X. Bostick for the examination and correlation of samples and cores from wells drilled on Arcadia and Vacherie domes, and for other valuable assistance, and to A. L. Selig, for examination and correlation of numerous samples from wells and outcrops, and for assistance and valuable suggestions too numerous to mention. L. W. Stephenson, of the U. S. Geological Survey, has identified many of the fossils collected from the salt domes. H. V. Howe, of the Louisiana State University, has identified many of the Tertiary fossils and assisted the writer in many other ways. The many helpful suggestions offered by Sidney Powers have been invaluable. The whole paper has been read and criticized by J. P. D. Hull.

EXPLOITATION

Long before the coming of the white man to northern Louisiana, the Indians came to Drake's, King's, Bistineau, and other salt domes for their supply of salt. Pottery débris, evidencing Indian occupation, is abundant on some of the salt domes, and the accounts

of the earliest travelers in this region contain many references to the Indian trade in salt.

TABLE I

WELLS DRILLED ON THE INTERIOR SALT DOMES OF LOUISIANA

Company	Farm	Number	Location*	Year Completed	Total Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
Arcadia:							
Arcadia Oil Co.	Anderson	1	29, 18 N., 5 W.	1920	2,257	No	No
Arcadia Syndicate	White	1	29, 18 N., 5 W.	1922	1,435	1,282	1,400
Arcadia Syndicate	Madden	1	19, 18 N., 5 W.	1922	2,000	1,412	1,443
Arcadia Syndicate	Pentecost	1	20, 18 N., 5 W.	1922	4,012	2,678	2,755
Arcadia Syndicate	McGuire	1	30, 18 N., 5 W.	1923	3,450	3,040	3,151
Arcadia Syndicate	Anderson	2	29, 18 N., 5 W.	1923	3,225	No	No
Vacherie:							
Standard Oil Co.	Jordan	1	16, 17 N., 8 W.	1922	807	709	799
Standard Oil Co.	Stephens	1	21, 17 N., 8 W.	1923	788	658	777
Standard Oil Co.	Scott	1	21, 17 N., 8. W.	1923	2,558	No	No
Standard Oil Co.	Woodard and Walker	1	16, 17 N., 8 W.	1924	1,872	No	No
Bistineau:							
Gulf Refining Co.	Bistineau	1	2, 17 N., 10 W.	1910	2,523	No	No
Gulf Refining Co.	Bistineau	2	35, 18 N., 10 W.	1913	2,305	1,375	1,500
American National Oil Co.	Crichton	1	26, 18 N., 10 W.	1920	3,245	No	No
King's:							
The Pardee Co.	Fee	1	35, 15 N., 8 W.	1914	404	161	175
The Pardee Co.	Fee	2	26, 15 N., 8 W.	1915	.....	.....	No
The Pardee Co.	Fee	3	26, 15 N., 8 W.	1915	1,442	1,413	No
Louisiana Oil Refining Corp.	Huckaby	1	27, 15 N., 8 W.	1921	2,232	?	No
Louisiana Oil Refining Corp.	Huckaby	2	27, 15 N., 8 W.	1921	2,505	No	2,228
Rayburn's:							
Hodge-Hunt Lbr.	Fee	2	29, 15 N., 5 W.	1923	3,003	No	No
Hodge-Hunt Lbr.	Fee	3	30, 15 N., 5 W.	1923	277	65	115
Price's:							
Vivian Oil Co.	Bodcau	1	25 13 N., 4 W.	†	†	†	†
Drake's:							
Savage Bros.	Artesian well	.....	21, 12 N., 5 W.	1864–65	1,011	?	No
Savage Bros.	Fee	1	21, 12 N., 5 W.	1906	2,262	290	900
Savage Bros.	Fee	2	21, 12 N., 5 W.	1907	1,510	?	No
Winnfield Quarry:							
Tampico Oil Co.	So. Min. Co.	1	19, 11 N., 3 W.	1914	2,112	?	No
Cody Petroleum Co.	So. Min. Co.	1	19, 11 N., 3 W.	1922	1,100	Surf.	999
Cody Petroleum Co.	So. Min. Co.	2	24, 11 N., 4 W.	1922	1,242	No	No
Gulf Refining Co.	So. Min. Co.	1	30, 11 N., 3 W.	1923	4,021	?	No
Coochie Brake:							
Cody Petroleum Co.	Edenborn	1	31, 10 N., 4 W.	.....	1,912	No	No
Cody Petroleum Co.	Edenborn	2	31, 10 N., 4 W.	.....	3,000	No	No
Cedar Creek:							
The Pardee Co.	Fee	1	31, 11 N., 2 W.	1914	1,120	806	No
The Pardee Co.	Fee	2	31, 11 N., 2 W.	1914	2,650	No	No
The Pardee Co.	Fee	3	31, 11 N., 2 W.	1917	800	Yes	No
Pace *et al.*	Pace	1	31, 11 N., 2 W.	1903–7	220 to 1,000	No	No
Pace *et al.*	Pace	2	31, 11 N., 2 W.	1903–7		Yes	No
Winnfield Oil Co.	Butler	.....	31, 11 N., 2 W.	1903–7		Yes	No
Winnfield Oil Co.	Clifford	.....	31, 11 N., 2 W.	1903–7		?	No

* Section, Township, and Range, in this and following Tables.
† No record available.

The early settlers made salt for local consumption, but it was not until the time of the Civil War, when the federal blockade of the southern ports became effective, that salt-making commenced on a large scale. People then came from Texas, Arkansas, Mississippi,

and even more distant states to engage in salt-making. Bistineau, King's, Rayburn's, and Drake's salt domes were the largest producers, but salt was made in considerable qualities, also, at several other localities during this period. Accurate records of the production are not available, but it is estimated that in 1862, 1863, and 1864 there were 1,000 to 1,500 people engaged in salt-making at Bistineau. The daily production from Rayburn's for the same period is estimated to have been 1,000 to 1,200 bushels. Production records and estimates are not available from the other domes, but it is known that King's, Drake's, and Price's domes were large producers of salt, and this fact is borne out by the number of brine wells and remnants of evaporating equipment found at these places. With the close of the war the making of salt on a large scale ceased.

Limestone was quarried at Winnfield before the Civil War and burned for lime, and at the present time a crushing plant with a daily capacity of more than 1,000 tons is in operation.

Exploration for oil and gas began in 1903, shortly after the discovery of oil at Spindletop, when the Winnfield Oil Company commenced the drilling of a well in Sec. 30, T. 11 N., R. 2 W., on Cedar Creek dome. This well penetrated cap rock at a depth of about 800 feet, and continued to a depth of about 900 feet, where, because of the hard rock and inadequate drilling equipment, it was abandoned.

The first deep well, reaching a depth of 2,523 feet, was drilled in 1910 by the Gulf Refining Company. It was located in Sec. 2, T. 17 N., R. 10 W., on the south flank of Bistineau dome. In all, more than 30 wells, all failures, have been drilled on or around the salt domes for the purpose of testing their oil and gas possibilities. A few of these have had small shows of oil; some gas; but none of sufficient volume to be considered a commercial well. Arcadia dome, with seven wells, and Vacherie dome, with four wells, have received the most thorough tests. Here are listed the wells drilled on and around the different domes (Table I).

GENERAL GEOLOGY

REGIONAL PHYSIOGRAPHY

The interior salt domes lie in that physiographic province of the Coastal Plain known as the hill lands of Louisiana. It is a dissected

plain which slopes gently gulfward. It has an altitude of 350 to 400 feet above sea-level in the northern part, and 250 feet in the southern part of the salt-dome area. The region is drained by southward-flowing streams which empty into Red River to the west and south. From west to east these streams are Bayou Dorcheat, Black Lake Bayou, Saline Bayou, and Dugdemona Bayou. They flow in wide flat valleys, characteristic of the streams in northern Louisiana.

NAME OF DOME	CAP ROCK		SALT CORE			TOPOGRAPHIC EXPRESSION	GEOLOGY		AMOUNT OF UPLIFT IN FEET	DIAMETER OF UPLIFT IN MILES	WELLS	
	FOUND	DEPTH IN FEET	FOUND	DEPTH IN FEET	DIAMETER OF CORE IN MILES		NORMAL SURFACE FORMATION	OLDEST FORMATION EXPOSED AT THE SURFACE			DEEPEST ON TOP OF DOME	DEEPEST ON THE SIDE OF DOME
ARCADIA	X	1588	X	1400	1	NONE	ST. MAURICE	ARKADELPHIA	2000	4	3000	4913
BETHEAU	X	1375	X	1580	½	CENTRAL SALINE	CANE RIVER	MARLBROOK	2000	3	2305[a]	3245
CEDAR CREEK	X	709	No		¾	CENTRAL SALINE	YEGUA	ST. MAURICE	3000	3	1120	2430
COCHRIE BRAKE	No		No		—	CENTRAL DEPRESSION	YEGUA	ST. MAURICE	[b] —	2½	NONE	3100
DRAKE'S	X	290	X	909	½	CENTRAL SALINE	SPARTA SAND	WILCOX	2000	3	2265	1810
KING'S	X	161	X	172	¾	CENTRAL SALINE	CANE RIVER	MARLBROOK	2100	3	494	2585
PRICE'S	No		No		½	CENTRAL HILL	SPARTA SAND	WILCOX	2000	2½	NONE	2134
PROTHRO	No		No		¾	CENTRAL DEPRESSION	SPARTA SAND	BLOSSOM SAND	2800	3½	NONE	NONE
RAYBURNS	X	65	X	115	½	CENTRAL SALINE	SPARTA SAND	BLOSSOM SAND	2700	3	277	3003
VACHERIE	X	655	X	777	½-¾	CENTRAL DEPRESSION	SPARTA SAND	ARKADELPHIA	1500	4½	847	2588
WINNFIELD	X	Dry hole	X	888	½	CENTRAL DEPRESSION	YEGUA	WILCOX	[c]	3	1100	4051
DIXIE	No		No		—	NONE	YEGUA	SPARTA SAND	[c]	3	NONE	4048

(a) A short distance down the flank. (b) Uplift greater than indicated in outcrops. (c) Uplift not determined but amounts to several hundred feet.

FIG. 4.—Table giving the essential characteristics of the interior salt domes of Louisiana.

SURFACE MANIFESTATIONS OF SALT DOMES

The surface manifestations of the salt domes of this region are the result of truncation of highly localized structures of great relief. Truncation, assisted in some places where the salt mass lies near the surface by the removal of salt in solution, has produced the peculiar topographic forms consisting of a central basin area encircled by hills. This form, which is the most common in the region, is well illustrated by Rayburn's and Prothro salt domes (Figs. 15 and 11). Another topographic form, not uncommon in Texas but represented in this region only by Price's salt dome (Fig. 17), consists of a central hill surrounded by a circular drainage system. Where truncation is deep and the salt mass near the surface, salt licks, or salines, barren or sparsely covered with vegetation, are usually grouped around the periphery of the central basin. Characteristic salt-dome features are steeply tilted rocks, outcrops of

formations older than those usually found in the region, and springs of water, either fresh, slightly brackish, or mineralized with sulphur or alum.

STRATIGRAPHY

The Claiborne group of the Eocene is found at the surface in the salt-dome region of northern Louisiana, but older Eocene beds, as

FIG. 5.—Topographic map of Arcadia salt dome

well as strata of Cretaceous age, appear at the surface in isolated outcrops on the domes. The oldest beds penetrated in the deep wells on and around the salt domes belong to the Comanchean series of the Cretaceous.

The brief discussion of the stratigraphy that follows is based largely on information obtained from the deep wells. The character and thickness of the several lithologic units can be determined with

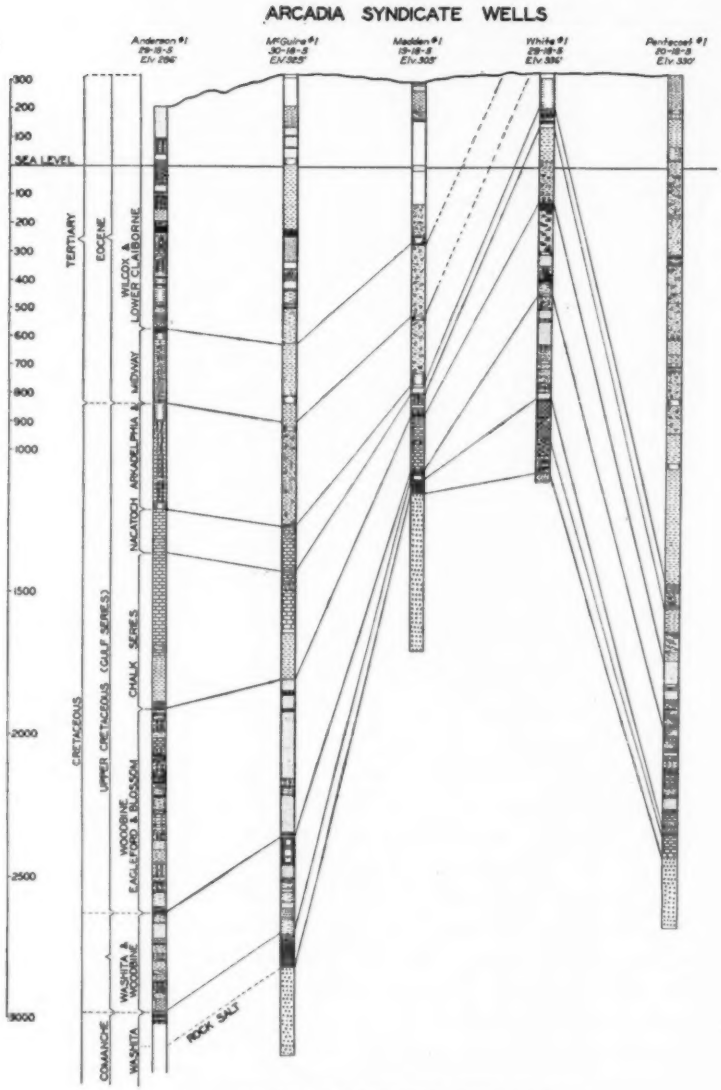


FIG. 6.—Well section on Arcadia salt dome

considerable accuracy, but correlation with the standard section of Texas is as yet a mooted question, and strongly emphasizes the need of systematic stratigraphic work, not only on material available from this region, but also in southern Arkansas, where these beds crop out.

A detailed discussion of the stratigraphy of each dome is given under the description of the salt domes.

The generalized stratigraphic section of this region is here given.

GENERALIZED SECTION OF FORMATIONS IN THE SALT-DOME REGION OF NORTHERN LOUISIANA

System	Series	Group	Formation	Thickness (Feet)
Quaternary	Recent			
	Pleistocene			
Tertiary	Eocene	Claiborne	Yegua	200–400
			St. Maurice	100–150
			Sparta sand	400–550
			Cane River	75–150
			Wilcox	800–2,500
			Midway	450±
Cretaceous	Gulf (Upper Cretaceous)		Arkadelphia	150–200
			Nacatoch	150–200
			Marlbrook, Annona chalk, Brownstown	550–650
		Bingen	Undifferentiated (Blossom sand at the top)	800–1,000
	Comanchean (Lower Cretaceous)	Washita, Fredericksburg, Trinity	Undifferentiated	3,000+

GULF SERIES (UPPER CRETACEOUS)

Following an erosion interval of some duration, Upper Cretaceous sedimentation began with a basal sand (Woodbine). The alternation of sand, shale, and chalk indicates many changes in the rela-

tive depth of the sea wherein these sediments were deposited, but no distinct unconformities within the series are recognizable. The lateral variation in the character and thickness of the basal beds (Bingen group) suggests that the sea advanced from the south and west, and that the sediments were derived from the Appalachian rather than from the Ozark mountain system.

The work of revising the stratigraphy of east Texas and south Arkansas is now under way; until this work is completed and correlated with the Louisiana sections, only a tentative correlation can be made for this region. The Gulf series is divided as follows:

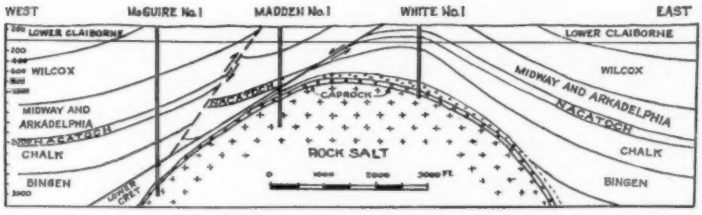


FIG. 7.—Cross-section of Arcadia salt dome

GENERALIZED SECTION OF UPPER CRETACEOUS FORMATIONS IN THE SALT DOME REGION OF NORTHERN LOUISIANA

Gulf Series (Upper Cretaceous)		Feet
Arkadelphia formation		150– 200
Nacatoch formation		150– 200
Marlbrook formation Anona chalk Brownstown formation	Marl and chalk series	550– 650
Bingen group (including Blossom sand at the top)		800–1,000

BINGEN GROUP

The Bingen group is herein used to designate those formations which, in the earlier publications, were correlated with the Blossom sand, Eagle Ford shale, and Woodbine sand. The name Bingen was applied to the basal Upper Cretaceous beds in southwestern Arkansas by Veatch[1] who considered them the equivalent of the Woodbine

[1] A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, 1906.

sand and Eagle Ford shale of Texas. Later stratigraphic work has proved that in part, at least, the beds formerly correlated with the Eagle Ford are younger in age, but until further stratigraphic work is done, it is not possible to differentiate the beds herein grouped in the Bingen.

The Bingen group in the salt-dome region is in a general way divisible into these members: (1) sand 75–100 feet thick (Blossom sand), (2) marine shales in western part, sandy shale in eastern part, and (3) basal sand and clay.

The basal members usually begin with a red-clay member 10–40 feet, but locally as much as 100 feet, in thickness. Above this bed are 75–150 feet of alternating beds of sand, shale, and sandy shale in which plant remains and thin lignite partings are common. Chloritic material is present locally and accounts for the greenish and purplish tints of some of the sands in this member of the Bingen group.

The succeeding 600–700 feet of beds consist of marine shale and sandy shale. The shale predominates in the western part, and sandy shale in the eastern part, of the salt-dome region. None of the deep wells has penetrated these beds in the southern part of the area. The shales are gray to dark colored, and are in part chalky and calcareous. On the west side a thin limestone bed near the base is present in some places. Northeastward from this region these beds thin rapidly and are represented by sands which cannot be distinguished from the sands above and below.

The upper member of the group consists of 75–200 feet of sand, commonly known as the Blossom sand. It underlies all of this region but is known to outcrop at Rayburn's salt dome in Sec. 31, T. 15 N., R. 3 W., and at Prothro salt dome in Sec. 18, T. 14 N., R. 6 W. It is particularly well exposed in the latter locality. Where it outcrops in Louisiana it is a greenish-gray calcareous sandstone and, according to Ross,[1] who examined several samples from the outcrops and drill cores, it is made up of rounded quartz and novaculite, angular feldspar, and grains of igneous rock. It represents a horizon of volcanic tuffs that have been mixed with detrital material. The upper few feet of the sand is consistently coarse, often containing

[1] Clarence S. Ross, personal communication, July 22, 1924.

pebbles $\frac{1}{4}$–$\frac{3}{4}$ inch in diameter. The following well record illustrates the character of the Bingen group in the north-central part of the salt-dome region.

SECTION OF BINGEN IN ROXANA PETROLEUM CORPORATION—BRYAN NO. 1

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Blossom Sand:		
Sand	5	2,776
Sand, salt water	4	2,780
Hard sand	1	2,781
Fine soft sand with shale streaks	10	2,791
Sand	155	2,946
Sand and bowlders	2	2,948
Gumbo	8	2,956
Hard shale	20	2,976
Shale and bowlders	24	3,000
Sticky shale	5	3,005
Bowlders	10	3,015
Gumbo	3	3,018
Hard limestone	10	3,028
Broken lime and shale	14	3,042
Sandy shale	13	3,055
Sand and bowlders	30	3,085
Tough gumbo	9	3,094
Sand and bowlders	14	3,108
Hard limestone	9	3,117
Broken limestone and shale	10	3,127
Shale and gumbo, blue and gray	73	3,200
Broken limestone	20	3,220
Shale	67	3,287
Hard sand and gravel	13	3,300
Sandy shale, fossiliferous	53	3,353
Hard shale	37	3,390
Sandy shale	10	3,400
Sand	15	3,415
Shale and gumbo	24	3,439
Sandy shale	2	3,441
Hard shale	28	3,469
Sandy shale	3	3,472
Hard dark shale	53	3,525
Shale, sand streaks	38	3,563
Shale and gumbo	29	3,592

Sec. 30, T. 17 N., R 6 W.	Thickness (Feet)	Depth (Feet)
Hard sand	1	3,593
Shale	23	3,616
Sand	24	3,640
Gumbo	11	3,651
Sand	18	3,669
Hard shale, sand streaks	51	3,720

CHALK AND MARL SERIES

Above the Bingen is a series of marl and chalk beds aggregating 550–600 feet in thickness. In the order of their deposition, these beds have been named the Brownstown marl, Annona chalk, and Marlbrook marl. The last-named formation includes the Saratoga-chalk member. The age relationship between these beds and the chalk beds of northeast Texas has not been determined. The beds are not normally at the surface in northern Louisiana, but isolated outcrops are found on several of the salt domes and are particularly well exposed on Rayburn's and Prothro salt domes in Bienville Parish.

The lower 150–200 feet of these beds consist of yellowish-green clay-marl with some interbedded, impure chalk. The upper 20–50 feet are gray sand and sandy clay. The succeeding 75–100 feet are hard, white chalk, and the upper portion of this series consists of shale, marl, and chalk. The amount of chalk is variable, but is most abundant in the southern and western parts of the salt-dome region. The following is a typical well record of this series:

SECTION OF CHALK SERIES IN ROXANA PETROLEUM CORPORATION—BRYAN NO. 1

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Chalky shale	30	2,190
Sticky shale	7	2,197
Chalky shale	21	2,218
Gumbo	10	2,228
Chalky shale	4	2,232
Limestone (hard chalk)	81	2,313
Chalk	101	2,414
Chalky shale	21	2,435
Chalk and sand	2	2,437
Broken limestone	4	2,441

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Chalky shale	35	2,476
Chalk	5	2,481
Chalk and limestone	59	2,540
Shale and gumbo	78	2,618
Sandy shale	9	2,627
Shale and gumbo	44	2,771

NACATOCH FORMATION

The Nacatoch formation is not known to crop out in Louisiana, although on some of the salt domes it occurs at very shallow depths below the surface. In the well logs it appears as limestone with interbedded thin sandstone members. In the southern part of the salt-dome region only closely cemented fine sand is present. The average thickness of the Nacatoch is about 200 feet.

ARKADELPHIA FORMATION

The uppermost Cretaceous of this region consists of 150–200 feet of dark-colored clays and chalky shales. In this formation were formerly included 300–400 feet of clays belonging to the Midway formation.

EOCENE

The Eocene sediments of this region comprise several hundred feet of sand, clay, marl, and lignite. These sediments were deposited under varying conditions, according as the strand line migrated back and forth over this region. The Eocene has been divided as follows:

GENERALIZED SECTION OF EOCENE FORMATIONS OF NORTHERN LOUISIANA

Claiborne group:	Feet
Yegua formation	200– 400
St. Maurice beds	100– 150
Sparta sand	400– 550
Cane River beds	75– 150
Wilcox formation	800–2,500
Midway formation	400+

MIDWAY FORMATION

The Midway formation underlies all of northern Louisiana, but does not appear at the surface unless it is on some of the salt domes, where lithologically similar beds are tentatively correlated with it.

The Midway consists of gray and dark-colored clay shale, containing an abundance of siderite concretions and, in some places, a slight amount of fine sand. On the outcrop in southern Arkansas, and in wells drilled in the Bellevue field in Louisiana, a fossiliferous limestone bed occurs at or near the base of the formation. This bed probably is present in other localities, but has not been recognized in the wells. The thickness of the Midway is about 400 feet, but it may be somewhat more in the southern part of the salt-dome region.

WILCOX FORMATION

The Wilcox formation, described in the earlier literature of this region as the Lignitic stage and as the Sabine formation, has been described by several writers, of whom Harris, Veatch, and Berry[1] are the important contributors.

The outcrop of the Wilcox formation in Louisiana extends from southern Sabine Parish to the Arkansas line, and from the Texas line to some miles east of Red River. It also crops out on some of the salt domes, notably on Prothro dome in Bienville Parish.

The Wilcox deposits of the salt-dome region consist of more or less extensive lenticular beds of sand and clay. The sands, which predominate, are commonly laminated, but also cross-bedded and massive in structure. Thin laminae-like partings of ferruginous sandstone, clay balls, and rounded sand concretions are commonly present. Calcareous sandstone and siderite concretions are abundant, and characteristic of this formation. The clays are usually finely laminated, and range in color from light buff to black. A considerable amount of lignitic matter is present in the Wilcox formation, either finely disseminated through the mass or accumulated in lignite beds. Mica in fine flakes is a common mineral in this formation.

The marine phase of the Wilcox outcropping in Louisiana is generally limited to Sabine Parish. The lowest marine beds occur in

[1] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899*, Part 5 (1900), pp. 64–73 and 299–309; "The Tertiary Geology of the Mississippi Embayment," *Geol. Survey of Louisiana, Report of 1902*, Part VI (1902), pp. 11–17; A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), pp. 34–36; E. W. Berry, "The Lower Eocene Flora of Southeastern North America," *U. S. Geol. Survey Prof. Paper 91*, 1916.

the latitude of Marthaville and Pendleton, and are correlated with the Nanafalia beds, lowermost Wilcox, in Alabama. Deep wells drilled in Sabine Parish in recent years have revealed the presence of not less than 2,500 feet of sands, and clays, in part lignitic and fossiliferous, which occupy the interval between the Nanafalia horizons and the Midway clays. According to George Stevens,[1] fossils from these beds were identified by the U. S. Geological Survey as Wilcox. From their stratigraphic position they are obviously older than the oldest Wilcox in the Alabama section.

Marine Wilcox is not generally recognized in the wells which have been drilled in the salt-dome region, nor is any present on Prothro dome, where more than 800 feet of beds are exposed. Farther south, along the Angelina-Caldwell flexure where few wells have been drilled, the marine phase is probably as well developed as in Sabine Parish.

The Wilcox formation ranges in thickness from 800 feet in the northern part to more than 2,500 feet in the southern part of the dome region. The range in thickness is shown in a general way in Figure 3.

CLAIBORNE GROUP

The Claiborne group in Louisiana has been divided into an upper and a lower member. The upper member is represented by the Yegua formation, described in the earlier literature as the Upper Lignitic and the Cockfield formation. The lower member was designated as Lower Claiborne, or the Lower Claiborne stage, until 1920, when Harris[2] applied the name "St. Maurice formation" to the Lower Claiborne member. The name was taken from the type locality of St. Maurice, Natchitoches Parish, Louisiana. The St. Maurice formation, as defined by him, includes all of the beds above the Wilcox formation and below the Yegua formation.

The deep wells drilled in this region, many of which were carefully sampled and cored, have aided in giving a better understanding of the succession, character, and thickness of the Lower Claiborne beds than could be obtained from a study of the scattered outcrops.

[1] Personal communication.

[2] G. D. Harris, "Lower Tertiary of Louisiana," *Science*, New Series, Vol. 31 (1910), p. 502.

The accumulated data suggest that they are divisible, on lithologic and paleontologic grounds, into three distinct members, either one of which may be ranked as a formation. For convenience in describing the geology of the region the following names have been used to designate these divisions—Lower Claiborne: St. Maurice beds, Sparta sand, Cane River beds.

CANE-RIVER BEDS

In the Cane River are included the 75–150 feet of beds above the Wilcox formation and below the massive Sparta sand. The name Cane River, from the excellent exposures on Cane River at Natchitoches, Louisiana, was suggested by H. V. Howe.

These beds outcrop in a narrow belt trending northeast across southern Sabine and Natchitoches parishes. A few miles east of Red River the strike changes to northwest, and continues in that direction to the Arkansas line. The width of the outcrop is 3–7 miles.

An erosional unconformity separates the Cane River and Wilcox beds. The basal member consists of glauconitic sand and sandy clay, but in some places marine tuff is present at the base. Glauconitic clays predominate in the southern portion of the outcrop, but northward from Bienville Parish they become sandier, until, in northern Bossier Parish, they are represented entirely by sands, in part glauconitic, and containing a meager representation of the prolific fauna found farther south. The fauna of the Cane River beds have been described by Harris[1] and Vaughan.[2] Harris groups the fauna under the St. Maurice and Claiborne stage, and Vaughan makes the following statement concerning these beds: "For Alabama, Mississippi, and Louisiana, excepting Natchitoches, the species are very nearly the same in all of these states for this division of the Claiborne. and apparently all belong to that horizon of the Lower Claiborne called the Lisbon beds." Vaughan[3] lists the following species typical of the Cane River beds from Natchitoches, Louisiana: *Amphihelia*

[1] G. D. Harris, "Pelecypoda of the St. Maurice and Claiborne Stages," *American Paleontology*, Vol. 6 (1919), No. 31.

[2] T. W. Vaughan, "The Eocene and Lower Oligocene Coral Faunas of the United States," *U. S. Geol. Survey Monograph 39*, 1900.

[3] *Op. cit.*, p. 27.

natchitoensis Vaughan, *Madracis ganei* Vaughan, *Endopachys maclurii* (Lea), *Balanophyllia augustinensis* Vaughan.

From this statement it is obvious that Vaughan recognized a faunal province distinct from the remainder of the Lower Claiborne.

The Cane River beds, as shown in records of wells drilled east and southeast of the outcrop, are made up chiefly of glauconitic clays with subordinate beds of sand. The thickness increases slightly in the eastern and southeastern parts of the salt-dome region.

SPARTA SAND

This division of the Lower Claiborne is limited below by the Cane River beds and above by the lowest fossiliferous horizon of the St. Maurice beds. The name "Sparta sand" was used by Vaughan[1] in 1896 to designate certain sands and gravels which, from his description of their areal distribution, included the Sparta sand as defined above, as well as portions of the Catahoula sandstone of Oligocene age, and the Citronelle formation of Pliocene age.

The Sparta sand, owing to the steep dips along the Angelina-Caldwell flexure, outcrops in a narrow belt from Sabine River to the northern end of Saline Lake. From this point northward to the vicinity of Minden it has a width of 10–15 miles.

The lower half of the Sparta sand is made up chiefly of massive sand with interbedded subordinate members of laminated sandy clay. The massive sands are made up of quartz grains somewhat coarser than found in the Wilcox formation. The upper half contains a relatively greater amount of clay than the lower half. Massive sands alternate with beds of finely laminated sandy clay, in part lignitic and in many places containing fossil leaves. The upper 50 feet of beds contain a considerable amount of lignitic material and some thin lignitic beds which are particularly well exposed in the vicinity of the town of Bienville. The beds are commonly light colored, but, depending upon the amount of iron and carbonaceous matter, red- and brown-colored beds occur. Fossils are generally absent from the Sparta sand, but a few species of near-shore forms are found near the middle of the formation. The Sparta sand has a thickness of 400–500 feet, with the greater thickness in the northern part of the salt-dome region.

[1] T. W. Vaughan, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), p. 25.

ST. MAURICE BEDS

The St. Maurice includes the beds above the Sparta sand and below the Yegua formation, and is the equivalent of the upper part of the St. Maurice formation as defined by Harris.[1]

The St. Maurice beds, like the Cane River and Sparta sand, outcrop in a narrow belt across Sabine, Natchitoches, and Winn parishes. The outcrop gradually increases in width from Winnfield northward to Ruston on the Vicksburg, Shreveport & Pacific Railroad. The area north of the railroad, to the vicinity of the Arkansas line and eastward to the Ouachita River valley, is chiefly St. Maurice, although many remnants of the Yegua formation are present. This portion of northern Louisiana has not been mapped in enough detail to show the distribution of the St. Maurice and the Yegua formations.

The St. Maurice is made up of alternating beds of sands and clays. The sands predominate; they commonly range in color from light gray to red, but in some places are brown, owing to the carbonaceous matter they contain. In structure they are massive, cross-bedded, and laminated. They contain considerably more ferruginous sandstone than is present in the underlying Sparta sands. The clays are gray, green, red, and brown in color, depending upon the iron, glauconite, or carbonaceous content of the individual beds. The glauconitic beds are usually massive, but the sandier clays and the lignitic clays are often laminated. The basal and the upper beds are fossiliferous, and at least one other fossiliferous horizon occurs between the two horizons mentioned. The more perfect fossil shells and corals are found in the glauconitic clays and sands, but an abundance of fossil casts occur in the ferruginous concretions and in the thin ferruginous sandstone beds. The thickness of the St. Maurice beds ranges from 100 to 150 feet.

YEGUA FORMATION

The upper Claiborne is represented in this region by the Yegua formation, which, in the early Louisiana literature, was designated as Upper Lignitic and Upper Claiborne. Vaughan,[2] in 1896,

[1] G. D. Harris, "The St. Maurice and Claiborne Stages," *American Paleontology*, Vol. 6 (1919), No. 31.

[2] T. W. Vaughan, "A Brief Contribution of the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), pp. 21–22.

applied the name "Cocksfield Ferry beds," and Veatch,[1] in 1905, used the name "Cockfield formation." The equivalent beds in Texas were named the Yegua formation by Dumble[2] in 1892. As the latter name had priority it was adopted by the U. S. Geological Survey Committee as the geologic name.

The Yegua formation outcrops in a narrow belt across southern Sabine Parish. Beginning in the southeast corner of Winn Parish, the outcrop gradually increases in width to the east and north. In the vicinity of Winnfield the strike changes to north, and these beds are exposed in a wide belt as far as the Vicksburg, Shreveport & Pacific Railroad. Their eastern extension is limited by the Ouachita River valley.

The Yegua formation is predominantly sandy; massive, light-colored sands alternate with laminated and thin-bedded sandy clays and lignitic clay. The beds are generally light colored, but often red and brown. The maximum thickness of the Cockfield does not exceed 500 feet. Fossil leaves are present in the lignitic clays in many places, but marine fossils are not found in this formation.

VACHERIE SALT DOME

LOCATION AND HISTORY

Vacherie salt dome is located about 4 miles east of the town of Heflin. The center of the uplift lies on both sides of Webster-Bienville Parish line, in Secs. 16 and 21, T. 17 N., R. 8 W. It is 10 miles southeast of Bistineau, and 16 miles southwest of Arcadia salt dome.

Discovery of this dome was made as the result of field work by S. C. Stathers, chief geologist of the Standard Oil Company of Louisiana, who mapped this area in 1921. The writer is indebted to Mr. Stathers and his department for most of the data concerning the wells drilled on this dome. Vacherie was proved to be a salt dome in August, 1922, when the Standard Oil Company of Louisiana, drilling in Sec. 16, T. 17 N., R. 8 W., Webster Parish, struck rock salt at 799 feet. The second well was drilled just across the line in Section 21, Bienville Parish, where the salt was found at a depth of 777 feet.

[1] A. C. Veatch, "A Report on the Underground Waters of Louisiana," *Geol. Survey of Louisiana, Report of 1905, Bull. No. 1* (1905), pp. 31–32.

[2] E. T. Dumble, "Report on Brown Coal," *Geol. Surv. of Texas* (1892), pp. 148–54.

Two more wells were drilled, one on the north and the other on the south flank of the dome. They were abandoned in the Lower Cretaceous and did not reach the salt mass.

TOPOGRAPHY

Vacherie dome (Fig. 8) is in an area of rugged hill lands, characteristic of the outcrops of the Sparta sand, in the northern part of the salt-dome region. The center of the dome is represented by a basin across wh:h Vacherie Creek flows eastward in a broad, flat valley, and from which it passes through a narrow steep-sided valley

TABLE II

WELLS DRILLED ON VACHERIE SALT DOME

Company	Farm	Number	Location	Year	Total Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
Standard Oil Co..	Jordan	1	16, 17 N., 8 W.	1922	897	709	799
Standard Oil Co..	Stephens	1	21, 17 N., 8 W.	1923	788	658	777
Standard Oil Co..	Scott	1	21, 17 N., 8 W.	1923	2,558	No	No
Standard Oil Co..	Woodard and Walker	1	16, 17 N., 8 W.	1924	1,872	No	No

in the high encircling hills. The sides of this basin slope gently upward to the base of the high encircling hills, which rise 150 feet above the valley of Vacherie Creek. The center of the low area is underlain by Midway and Arkadelphia clays; the surrounding parts, by Wilcox sands and clays. Radial streams rising on the flanks of the high hills flow into Vacherie Creek from all directions. Fresh-water springs are numerous around the base of the hills, and a spring of sulphur water is present in the SW. $\frac{1}{4}$ of Sec. 15, T. 17 N., R. 8 W. This spring, according to people living in the vicinity, has increased several times in volume during the past fifteen years.

SURFACE GEOLOGY

The Sparta sand outcrops in the high encircling hills. The Cane River beds are generally concealed by the inwash of sand from the overlying Sparta beds, but a good outcrop occurs in the side of the road near the SE. cor. of SW. $\frac{1}{4}$ of SW. $\frac{1}{4}$, Sec. 9, T. 17 N., R. 8 W. It consists of fossiliferous, glauconitic, green clay. The dips are 18 degrees NE. Another outcrop of Cane River beds is near the NW.

cor. of SE. $\frac{1}{4}$, Sec. 15, T. 17 N., R. 8 W. This bed is less calcareous than the first described, but consists of typical glauconitic clay. The Wilcox formation is exposed in several places, but where the Cane River beds are concealed, it is not easily distinguished from the

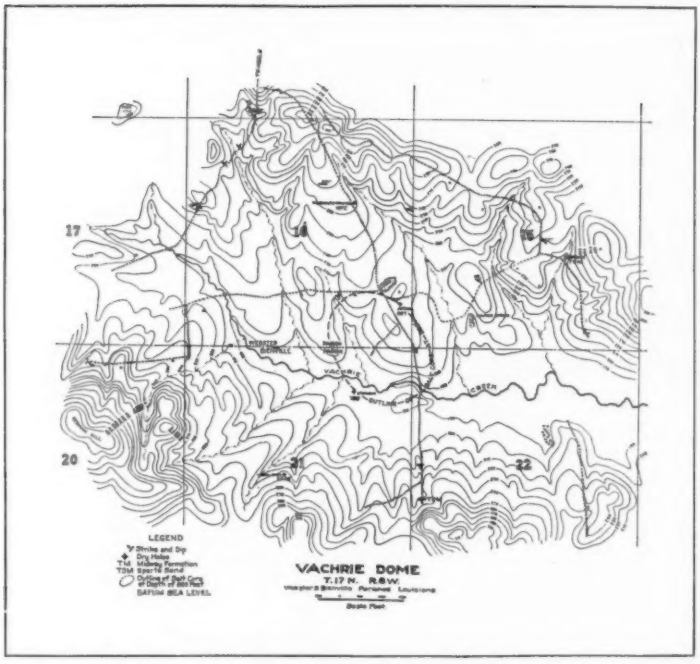


FIG. 8.—Topographic map of Vacherie salt dome showing characteristic central basin.

Sparta sand. It outcrops along the road in the NW. $\frac{1}{4}$, Sec. 16, T. 17 N., R. 8 W., but is best exposed in the ditches along the road which parallels the W. line of Sec. 22, T. 17 N., R. 8 W. It is made up of massive, grayish-blue clays which are highly fractured. Ferruginous clay and ironstone concretions are abundant in these beds, and sometimes contain leaf impressions. Bedding planes are poorly developed and the dip is not determinable, but appears to be high. The Midway and Arkadelphia formations outcrop in extensive

areas in the center of the dome. They are in most places covered with a veneer of sand and gravel. Because of their lithologic simi-

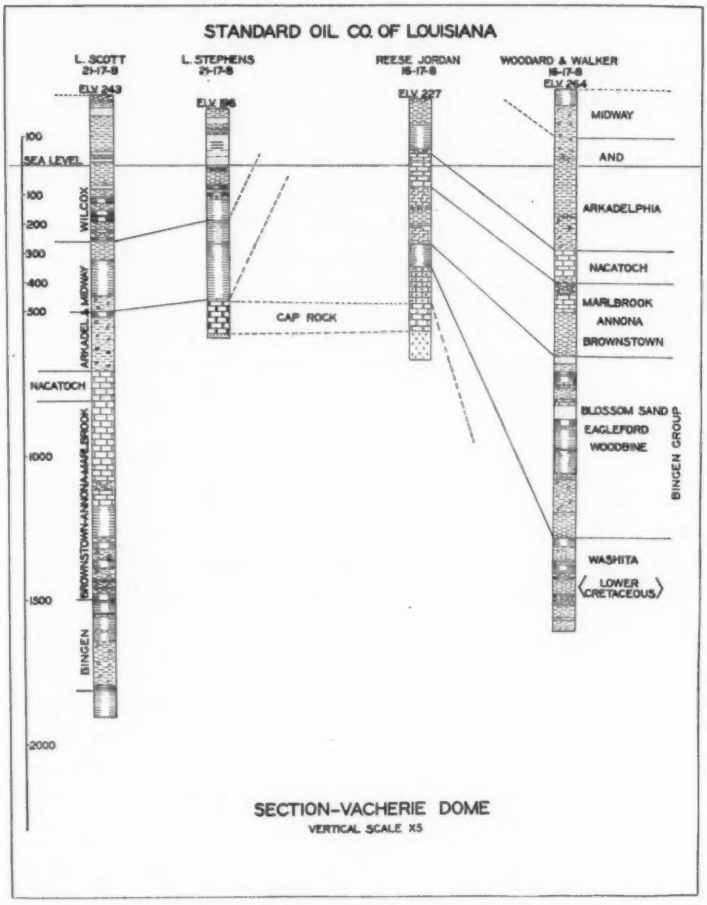


FIG. 9.—Well sections on Vacherie salt dome

larity and the faulting of these beds, their relative extent cannot be determined. The most important outcrops are shown in Figure 8.

UNDERGROUND GEOLOGY

Four wells were drilled on this dome by the Standard Oil Company of Louisiana. Reece Jordan No. 1, in Section 16, the first well drilled, started in the Arkadelphia formation and reached rock salt at a depth of 799 feet. L. Stephens No. 1, located in Section 21, started in the Wilcox formation and found rock salt at 777 feet. L. Scott No. 1, in Section 21, and Woodard & Walker No. 1, in Section 16, were abandoned in the Washita group of the Lower Cretaceous at depths of 2,558 feet and 1,872 feet, respectively. These wells were drilled under the supervision of Mr. Stathers, and no efforts were spared in securing complete records of the formations encountered. F. X. Bostick, the company's paleontologist, correlated the formations in these wells as follows (see Fig. 9):

GEOLOGIC SECTION OF REESE JORDAN NO. 1, SECTION 16

	Feet
Upper Cretaceous:	
Arkadelphia formation	0–188
Nacatoch formation	188–301
Chalk and marl	301–495
Bingen group	495–575
Lower Cretaceous:	
Washita group	575–709
Cap rock	709–799
Rock salt	799–897

GEOLOGIC SECTION OF L. STEPHENS NO. 1, SECTION 21

	Feet
Tertiary:	
Wilcox formation, Midway formation	0–658
Cap rock	658–777
Rock salt	777–888

GEOLOGIC SECTION OF L. SCOTT NO. 1, SECTION 21

	Feet
Tertiary:	
Wilcox formation	0–556
Midway formation, Upper Cretaceous: Arkadelphia formation	556– 953
Nacatoch formation	953–1,052
Chalk and marl	1,052–1,748
Bingen group	1,748–2,251
Lower Cretaceous:	
Washita group	2,251–2,558

GEOLOGIC SECTION OF WOODARD & WALKER NO. 1, SECTION 16

	Feet
Tertiary:	
Midway formation Upper Cretaceous: Arkadelphia formation	0– 550
Nacatoch formation	550– 675
Chalk and marl	675– 918
Bingen group	918–1,543
Lower Cretaceous:	
Washita group	1,543–1,872

CAP ROCK

The cap overlying the salt core is 90–120 feet thick in the wells drilled on the dome. It is white and light gray anhydrite with irregular dark gray and blue banding, quite similar in appearance to the calcite cap rock on the Winnfield and other salt domes.

LOWER CRETACEOUS

Washita group.—The oldest beds penetrated on this dome belong in the Washita group of the Lower Cretaceous. The most interesting, and perhaps the most significant, occurrence is found from 575 to 709 feet in the Jordan No. 1 well. It is a fossiliferous conglomerate made up of well-rounded red-, blue-, green-, and gray-colored limestone pebbles and smoky quartz and chert pebbles. The matrix is a fine-grained, angular quartz sand and green-colored argillaceous material. The mass is firmly cemented with calcite. The only recognizable fossil in this bed is *Ostrea navia* Hall, which is abundant in the Kiamitia clays, basal Washita of the Texas Lower Cretaceous section. This conglomerate is similar to that found in the same position relative to the cap rock on Arcadia salt dome.

The Washita beds found in Scott No. 1 well and Woodard & Walker No. 1 well are made up of shale, gumbo, sand, and limestone which, so far as can be determined from the inclosed fossils, probably are not older than the Weno clay, basal Upper Washita of the Texas section. The section penetrated in Scott No. 1 well is as follows:

DETAILED SECTION OF WASHITA BEDS IN SCOTT NO. 1, SECTION 21

	Depth (Feet)	Thickness (Feet)
Lower Cretaceous (Washita group):		
Gumbo	41	2,292
Shale	3	2,295
Sandy lime	5	2,300
Gumbo	18	2,318
Shale	13	2,331
Gumbo	9	2,340
Shale	20	2,360
Sand and limestone	2	2,362
Broken limestone	14	2,376
Broken lime and gumbo	27	2,403
Limestone and pyrite	29	2,432
Packed sand	26	2,458
Sandstone	14	2,472
Tough gumbo	19	2,491
Broken rock	2	2,493
Sandstone	10	2,503
Gumbo	39	2,542
Limestone	16	2,558

The Washita conglomerate present on Vacherie and Arcadia domes has not been recognized in the many deep wells which have penetrated this formation elsewhere in northern Louisiana.

UPPER CRETACEOUS FORMATIONS

The Upper Cretaceous section found in the wells drilled on this dome does not differ greatly in character from the normal section of the region. The wide difference in thickness of the beds is due chiefly to faulting, though stretching of the beds during folding may have affected the shale members in some slight degree.

STRUCTURE

The structure of Vacherie dome is typical of salt-dome structure of this region. The central salt core, slightly elongated northwest and southeast, is about 2,500 feet in diameter at a depth of 800 feet below the surface. The inclination of the salt surface is not known. The salt is surmounted by a cap of anhydrite 90 to 120 feet thick. The sedimentary beds involved in the uplift are arched and pierced by the intrusion of the salt. The total vertical relief of this dome is

about 1,600 feet, and the area affected by the uplift is about 4 square miles. The structure of Vacherie dome is complicated by faulting, more than any other dome in this region of which we have equally complete records. A cross-section of Vacherie dome is shown in Figure 10, constructed from well records and surface outcrops. The well sections, areal distribution of the beds at the surface, and the dips of these beds harmonize, so far as the incomplete data show. The faulting is mainly peripheral, and probably represents segments of the arch, formed by the intrusion of the salt core, which failed under the continued pressure applied from beneath.

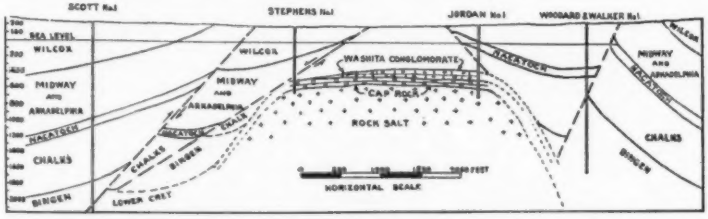


FIG. 10.—Cross-section of Vacherie salt dome showing faulting of sedimentary beds around the salt core.

PROTHRO SALT DOME

LOCATION AND HISTORY

Prothro salt dome is located 4 miles northwest of the town of Saline, in southern Bienville Parish. The center of the uplift is in Secs. 8 and 17, T. 14 N., R. 6 W. It is 8 miles southeast of King's and 5 miles southwest of Rayburn's salt domes.

This dome remained unknown until recently. In July, 1922, J. P. D. Hull, in company with J. L. Dormon, lawyer of Shreveport, Louisiana, visited this locality. Mr. Dormon was once a resident of Saline, where he had become familiar with the locality, and recognized the unusual character of the rock exposed. Mr. Hull mapped the essential geologic features of this dome, and the writer is indebted to him for much of the information here presented. In February, 1924, Mr. Hull accompanied Sidney Powers and the writer to this locality, and the name Prothro, from Prothro Mill Creek, located on the dome, was agreed upon. The dome has not yet been tested by drilling.

TOPOGRAPHY

Prothro dome (Fig. 11) consists of a central low, somewhat marshy, area one mile long and half a mile wide. The central area is encircled by an inner rim of low hills and an outer rim of higher

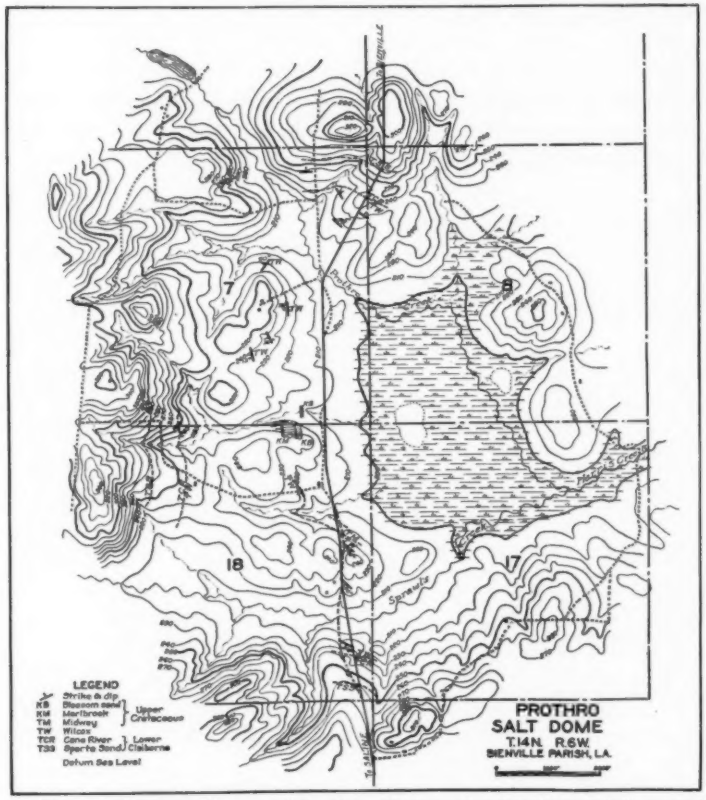


FIG. 11.—Topographic map of Prothro salt dome showing characteristic central basin and encircling rims of hills.

hills on the north, west, and south sides. The central low area has an altitude of 190–200 feet above sea-level, and the inner rim of hills is 40–50 feet higher. The outer rim of hills merges with the rugged hill lands of this area. Their elevation is from 310 to 350 feet, giving a total relief of 150 feet.

The central low area represents the highest part of the uplift, or that part of it underlain by the salt mass. Truncation of the dome by erosion and removal of salt by solution accounts for this marked basin. The Cretaceous and older Tertiary beds, including the Wilcox formation, are exposed in the low inner rim of hills. The high outer rim of hills is composed of Sparta sand, with Cane River beds at its base.

The salt-dome area is drained by Prothro and Sprawls creeks. Prothro Creek rises on the north side and enters the central basin on the northwest side. Sprawls Creek rises on the southwest side of the dome, flows eastward to enter the low area on the south side. Prothro and Sprawls creeks join near the east side of the dome to form Harris Creek, which empties into Saline Bayou about 2 miles farther east. Radial streams, fed by surface waters and springs, empty into the central basin from all directions.

SURFACE GEOLOGY

The geology of Prothro dome is of more than usual interest because of the fine section of Tertiary beds exposed there, which is not equaled in any locality in northern Louisiana. The Sparta sand, the normal formation at the surface in the locality, is exposed in the high hills encircling the dome. Cane River beds outcrop at the base of the high hills. The Wilcox formation and probably a part of the Midway formation crop out in the low inner rim of hills. Upper Cretaceous rocks more than 300 feet in thickness, including the Blossom sand at the base, crop out on the west side of the dome.

UPPER CRETACEOUS FORMATIONS

Beds of Upper Cretaceous age consisting of chalk, marl, and calcareous sandstone crop out in a small area in Secs. 7 and 18, T. 14 N., R. 6 W., where the following section was determined:

DETAILED SECTION OF UPPER CRETACEOUS ROCKS EXPOSED IN SECS. 7 AND 18, T. 14 N., R. 6 W.

	Feet
Upper Cretaceous:	
1. Fine-grained fossiliferous white chalk, thin bedded and fractured. Thin bed of sandy limestone at the base. Top concealed	160

	Feet
2. Somewhat chalky greenish-gray, fossiliferous clay. Weathers a reddish-brown	50
3. Fossiliferous, greenish-gray calcareous sandstone. Upper few feet contain many small pebbles	110

The sandstone at the base of this section is correlated with the upper part of the Bingen group, locally known as the Blossom sand. It is a greenish-gray calcareous sandstone, made up of rounded quartz grains and novaculite, angular feldspar, and grains of igneous rocks, which, according to Ross,[1] who examined several samples of this rock, represents a horizon of volcanic tuffs that have been mixed with detrital material. The upper few feet of this bed are decidedly coarse, containing many pebbles, $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. The strike is N. 20 W., and the dip 90 degrees.

The following fossils from the bed have been identified by L. W. Stephenson: *Cassidulus* sp., *Cucullaea* sp., *Inoceramus* sp., *Ostrea plumosa* Morton, *Trigonia* sp., *Serpula*(?), *Pugnellus* sp., *Placenticeras* sp., *Cardium* sp., *Crassitellites*(?), young individual. *membranipora* and *Herteropora* have been identified by R. S. Bassler. The sandstone bed is overlain by about 50 feet of yellowish-green marly clay, containing some argillaceous chalk. It is followed by 160 feet of fine greenish-white chalk, highly fractured and containing many small marcasite concretions. Calcite crystals, considerable vein calcite, and barite are associated with the chalk. The basal 3 or 4 feet of the chalk are sandy. The beds strike N. 20 W., and dip 80–85 degrees SW.

The following fossils collected from these beds were identified by L. W. Stephenson: *Inoceromus* sp., *Gryphaea vesicularis* Lamarck, *Anomia argentaria* Morton, *Cardium* (*Criocardium*) sp., *Ostrea cf. O. congesta* Conrad, *Exogyra cancellata* Stephenson, *Pholadomya*(?), *Exogyra costata*.

The chalk in the section is definitely Marlbrook in age, according to Stephenson,[2] and is about the horizon of the Saratoga chalk. The underlying clays appear to be older, and are perhaps the equivalent of a portion of the Brownstown formation.

[1] Clarence S. Ross, personal communication.

[2] L. W. Stephenson, personal communication.

TERTIARY FORMATION

The lower 100 feet of the beds above the Cretaceous have been tentatively assigned to the Midway formation. These beds are followed by about 1,000 feet of the Wilcox formation, which, in turn, is overlain by Cane River beds and Sparta sand of the Lower Claiborne group.

MIDWAY FORMATION

About 100 feet of bluish-gray clay exposed along the highway in the NE. ¼ of Sec. 18, T. 14 N., R. 6 W., are tentatively correlated with the Midway formation. The lower 50 feet are dark bluish-gray clay, containing a small amount of find sand. The succeeding 25 feet of beds consist of waxy yellowish clay, characterized by conchoidal fracture. The upper 25 feet are bluish-gray clay, with irregularly distributed patches of fine sand sparsely scattered through it. The beds strike N. 40 W., and dip 50 degrees NE.

WILCOX FORMATION

Isolated small outcrops of Wilcox beds are found in many places on the north and west sides of the dome, but the best and most complete section of these beds is along the highways in Sec. 18, T. 14 N., R. 6 W., where the following section is shown:

DETAILED SECTION OF WILCOX BEDS IN SEC. 18, T. 14 N., R. 6 W.

	Thickness (Feet)
Wilcox formation:	
1. Bluish-green sandy clay with partings of ferruginous sand	200
2. Massive, cross-bedded, red sand with ferruginous concretions, thin lenses, and balls of light-colored clay	150
3. Yellow sandy clay with small fragments of limonite and thin partings of ferruginous sandstone	450
4. Yellow and gray clay, thinly laminated, with rounded sand concretions 1 to 2 inches in diameter	25
5. Gray, slightly sandy clay, laminated, leaf impressions	75
6. Light-colored and mottled sandy clay; limonite and siderite concretions abundant in the lower 50 feet	100

The basal bed is light-colored, massive sandy clay in part mottled red and white. Limonite and siderite concretions are scattered through the mass, but are most abundant toward the base. The concretions range in size from a few inches to more than 2 feet in diameter. This bed is about 100 feet thick; it strikes N. 36 W., and dips 45 degrees SW.

The succeeding 75 feet of beds are gray, laminated, slightly sandy clay. The laminae range from $\frac{1}{4}$ to 1 inch thick in the upper part and from 1 to 3 inches thick in the lower part, of the beds. Leaf impressions and rounded sand concretions $\frac{1}{2}$ to 1 inch in diameter are scattered through these beds. The strike is N. 35 W., and the dip is 45 degrees SW.

The next 25 feet consist of thinly laminated yellow and gray clay. Round, sand-filled ferruginous concretions, 1–2 inches in diameter, occur in the beds.

The succeeding 450 feet are made up of yellow and gray sandy clays and clayey sand. Small fragments of limonite and many thin partings of ferruginous sandstone are present in these beds. The strike is N. 35 W., and the dip is 40 degrees SW.

The last-described bed is overlain by about 150 feet of massive cross-bedded red- and orange-colored sand, with many irregular thin lenses of grayish-green and white clay flakes. Clay balls and irregular-shaped ferruginous concretions are scattered through the sands. The dip and strike are not determined.

The uppermost beds of the Wilcox formations consist of bluish-green sandy clay, interbedded with thin beds of ferruginous brown sand and sandstone. These beds are about 200 feet thick. The strike is N. 30 W., and the dip is from 6 to 16 degree SW.

CLAIBORNE GROUP

Cane River beds.—Cane River beds crop out on the north, west, and south sides, as shown in Figure 12, but they are perhaps best exposed along the highway on the south side of the dome, in the SE. cor. of Sec. 18, T. 14 N., R. 6 W., where they consist of 50–75 feet of massive glauconitic clay.

At the base this glauconitic clay weathers with a mottled effect of red and green. It is slightly sandy and contains many fragments

of dark red chert thinly coated with chalcedony. The dip is undetermined, but the underlying Wilcox beds dip about 5 degrees SE.

It is followed by fossiliferous grayish-green marl. Near the base is a layer of gray concretionary limestone, which weathers to pale yellow on the outside. A layer of red-brown siderite, 1 to 2 feet

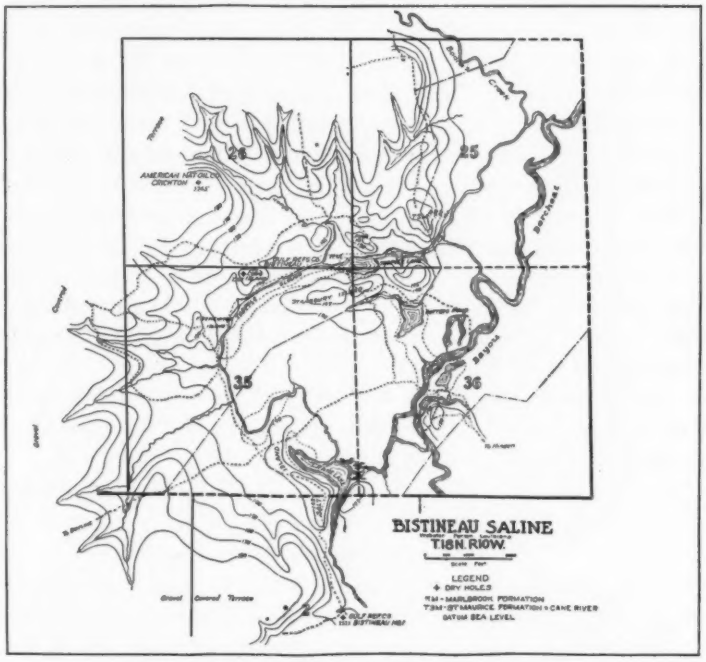


FIG. 12.—Topographic map of Bistineau salt dome

thick, occurs at the top of this member. Above the siderite layer are a few feet of pale greenish, massive, sticky clay, with irregular dark red-brown streaks through it. It weathers to pale yellowish-brown.

Because of the massive structure of these beds it is not possible to determine the dips accurately. The basal Cane River beds overlie Wilcox sands, dipping 5 degrees, and the dip apparently decreases rapidly southward.

Sparta sand.—The Sparta crops out in the high hills encircling the dome. It consists of massive red sands, with a few irregular lenses of light-colored clay. More than 100 feet of these beds are exposed around this dome.

STRUCTURE

The quaquaversal structure of Prothro dome is indicated in the dips of the rock outcropping on the north, west, and south sides. Although dips are lacking on the east side, there can be no reasonable doubt of their existence beneath the mantling of residual sand. The dome is deeply truncated by erosion. The central low area is perhaps in part due to the removal of salt by solution and a consequent lowering of the beds overlying it. The dip away from the central basin is steepest in the older rocks; the Blossom sand, the oldest formation exposed, stands vertical. The overlying chalk shows dips of 80 to 85 degrees. The Wilcox beds range from 50 degrees in the basal part to 5 degrees or less in the uppermost beds exposed. The strike of the different outcrops indicates a decided north-south elongation of this dome.

The vertical uplift determined on the Blossom sand outcrop is 2,800 feet, and the area affected by the uplift is slightly more than 3 miles in the direction of the longest dimensions of the dome.

BISTINEAU SALT DOME

LOCATION AND HISTORY

Bistineau salt dome is located in southern Webster Parish, about 4 miles south of the town of Doyline, on the Vicksburg, Shreveport & Pacific Railroad. The center of the uplift is in Sec. 35, T. 18 N., R. 10 W. It is 10 miles northwest of Vacherie salt dome and 12 miles southeast of the Bellevue oil field.

Evidences of Indian occupation are found on the south side of Potters Pond, which owes its name to the accumulations of pot débris about it. The Hodges brothers made some salt in 1850, but, except for a brief period in 1855 when drouth prevented boats from navigating the lake, it was not until the time of the Civil War that it was made in any considerable quantities. It is estimated that in the years 1862, 1863, and 1864 there were 1,000 to 1,500

people engaged in the making of salt at this locality. With the close of the war operation on a large scale ceased.

Bistineau salt dome was first described by Veatch[1] in his comprehensive report in 1902.

The salt wells drilled were shallow and, with one or two exceptions, did not exceed 20–25 feet in depth. The first well drilled for the purpose of testing the oil and gas possibilities of this dome was the Gulf Refining Company—Bistineau No. 1—in Sec. 2, T. 17 N., R. 10 W. Two more wells were drilled on the north flank of the dome, one of which reached rock salt.

TABLE III

WELLS DRILLED ON BISTINEAU SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
Gulf Refining Co.....	Bistineau	1	2, 17 N., 10 W.	2,523	1910	No
Gulf Refining Co.....	Bistineau	2	35, 18 N., 10 W.	2,305	1913	1,500
American National Oil Co.....	Crichton	1	26, 18 N., 10 W.	3,245	1920	No

TOPOGRAPHY

Bistineau salt dome (Fig. 12) lies beneath the bottom of the old raft lake[2] from which it derives its name. Since the removal of the raft, the levels of the lake have been lowered, and it is now represented in this area by Bayou Dorcheat.

The dome has a roughly circular central saline about one mile in diameter. On the east, where it merges into the bottom land along the bayou, it is distinguished by the barren, salt incrusted soil and the stunted growth of vegetation. The saline is in part barren and in part covered with a stunted growth of hawthorn, thick brush, and, here and there, a few cypress trees. Around the periphery of the saline is an almost continuous line of barren salt licks on which were located most of the old brine wells. Around the outer margin of

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 81–89.

[2] For description of the "raft lakes" of this period, see "Underground Water Supplies of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, by A. C. Veatch.

the central saline are several low, wooded mounds that appear as islands when the saline and bottom lands are inundated. Many of these mounds were named by the early salt-makers.

A gentle slope of 40 feet, in a distance of about half a mile, separates the saline from the gravel-covered terrace surrounding the dome on all but the east side, where it merges with the wide bottom of Bayou Dorcheat.

The salt-dome region is drained by Bayou Dorcheat, flowing in a general southward direction along the east side of the dome. Radial streams, of which Hodges Branch, on the northwest side, is the largest, empty into the saline. The radial streams combine to form a circular drainage system that follows the outer margins of the saline. This drainage system is well defined during the periods in which the waters of Bayou Dorcheat are confined to its channels.

The central saline represents the highest part of the uplift and closely outlines the area wherein the salt core lies at a moderate depth below the surface.

SURFACE GEOLOGY

Bistineau salt dome lies in the area of an extensive terrace deposit, probably of Pliocene age. Cane River beds, the normal surface formation, appear in a small outcrop on the north side of the dome, and the Marlbrook formation crops out in Tadpole Lake. The terrace deposits of sand and gravel have concealed all other beds on and around the dome.

The Marlbrook is represented by a bed of yellow clay, or soft limestone, poorly exposed in the shallow waters of Tadpole Lake, in the SE. cor., Sec. 26, T. 18 N., R. 10 W. The strike and dip of this bed are not determinable. The formation contains a number of Upper Cretaceous fossils, of which the following have been identified: *Gryphaea vesicularis*, *Exogyra costata*, *Lima* sp., *Pecten quinquenarius*, *Pecten simplicus*, *Cucullaea* sp.

That Cane River beds underlie the gravel-covered terrace material on the outer edges of the dome is proved by fossils found in shallow-water wells, but they are known at the surface only in one locality, in the SW. $\frac{1}{4}$ of Sec. 25, T. 18 N., R. 10 W. They consist of glauconitic sand and clay, with limonite concretions containing a typical Cane River fauna. These beds dip to the north, but neither the strike nor the angle of inclination could be determined.

UNDERGROUND GEOLOGY

Little information is available concerning the underground geology of Bistineau salt dome, as no well has been drilled on top of the dome in recent years, and only one well on the flanks. According to Veatch,[1] a well drilled near the mouth of Hodges Branch during the Civil War was reported to have struck rock, at 125 feet, which could not be penetrated. Fragments of rock similar to the cap rock at Rayburn's and other domes are found in this locality, and the presumption is that the rock, at a depth of 125 feet, represents the cap rock. The Gulf Refining Company's Bistineau No. 2 well, in Sec. 35, T. 18 N., R. 10 W., located on the north flank of the salt core, but only a short distance from the maximum elevation of the core, had the following section:

SECTION OF GULF REFINING COMPANY'S BISTINEAU NO. 2

	Thickness (Feet)	Depth (Feet)
Surface sand	16	16
Midway and Arkadelphia formations	444	460
Nacatoch formation	88	548
Marlbrook formation, Annona chalk, Brownstown formation	550	1,098
Bingen group	211	1,309
Bingen or Washita	78	1,387
Cap rock	105	1,492
Hard shale(?), probably rock salt	370	1,862
Rock salt	443	2,305

The Crichton No. 1 well in Sec. 26, T. 18 N., R. 10 W., 2,300 feet northwest of the Bistineau No. 2 well, found the top of the Nacatoch formation about 1,000 feet lower, indicating a dip to the north of about 25 degrees.

STRUCTURE

The salt licks distributed along the outer margin of the central saline area will give an approximate measure of the areal extent of the top of the salt core and overlying cap rock. The inclination of the sides of the salt core is not known. The sedimentary strata around the salt core are sharply flexed and pierced. The amount of uplift

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), p. 87.

measured on the outcrop of the Marlbrook formation is not less than 2,000 feet. The area affected by the uplift does not exceed 3 miles in diameter.

KING'S SALT DOME

LOCATION AND HISTORY

King's salt dome is located in the southwestern part of Bienville Parish, about 8 miles northwest of Prothro salt dome and 14 miles south of Vacherie salt dome. The center of the uplift is in Sec. 25, T. 15 N., R. 8 W. The Louisiana & Arkansas Railway traverses the dome from north to south, and the town of Castor is situated on the north flank of the uplift.

Evidences of Indian occupation are present in arrowhead, stone implements, and pottery débris. Salt-making for local consumption by the white settlers was begun by a Mr. King in the early forties of the last century. According to Hilgard,[1] King dug a shallow well and, striking rock, drilled it to a depth of 136 feet. During the Civil War the production of salt was greatly increased at this locality, but no information is available regarding the daily production for this period. With the close of the war the production of salt on any considerable scale ceased.

It is of historic interest that the Cretaceous of Louisiana was first recognized in this locality. Robertson,[2] in 1867, reported fossiliferous Cretaceous limestone from King's salt works, but Hilgard[3] was first to bring forward proof of this occurrence by finding *Exogyra costata* in the dump heaps at Big Lick.

King's salt dome was described in detail by Veatch[4] in 1902.

The old wells drilled for brine were shallow and, with the exception of King's well, previously mentioned, seldom exceeded a depth of 30 feet.

[1] E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans (1873), p. 29.

[2] J. B. Robertson, "Exploration and Memorial of the Honorable J. B. Robertson in Relation to the Agriculture, Mining, and Manufacturing Resources of the State; with a Report of the Joint Committee," *Doc. Second Session, Second Legislature, Louisiana, Report No. 23*, 1867.

[3] *Op. cit.*

[4] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 76–80.

Five wells have been drilled on this dome, as listed in Table IV.

These wells were all drilled on the north flank of the dome. Fee No. 1 reached rock salt at a depth of 161 feet, and Huckaby No. 2 at 2,228 feet; the others were abandoned in the cap rock.

TOPOGRAPHY

The central basin of King's salt dome (Fig. 13) is not so clearly outlined in the topography as the corresponding feature of some of the other salt domes of this region. On the west side a gentle slope

TABLE IV

WELLS DRILLED ON KING'S SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
The Pardee Co.....	Fee	1	35, 15 N., 8 W.	404	1914	161
The Pardee Co.....	Fee	2	26, 15 N., 8 W.	.....	1915	No
The Pardee Co.....	Fee	3	26, 15 N., 8 W.	1,442	1915	No
Louisiana Oil Refining Corp.....	Huckaby	1	27, 15 N., 8 W.	2,232	1921	No
Louisiana Oil Refining Corp.....	Huckaby	2	27, 15 N., 8 W.	2,505	1921	2,228

merges into an extensive terrace which stands 40–60 feet above the central saline area. On the south and east sides Sparta sand forms the hills which rise to an altitude of more than 300 feet above sea-level and 150 feet above the saline basin. The salt dome is drained by Bayou Castor, flowing in a general southwesterly direction through the central low area. Minor streams empty into it from all directions.

SURFACE GEOLOGY

King's salt dome is near the line of contact of Cane River beds and Sparta sand. Sparta sand is well exposed in the hills flanking the dome on the east and southeast sides. Cane River beds crop out on the gentle slope between the central basin and the high hills. The Wilcox formation is represented in this area by two small outcrops, both on the south flank of the dome. The best Wilcox exposure is in the ditch on the west side of the highway, about 30 feet south of the bridge over Bayou Castor. It is a somewhat sandy, laminated, light-colored clay. This bed dips to the southeast at an

angle of about 55 degrees. The Wilcox outcrop on Bayou Castor, near the northeast corner of Sec. 3, T. 15 N., R. 8 W., consists of laminated brown lignitic sand with thin streaks of dark lignitic clay.

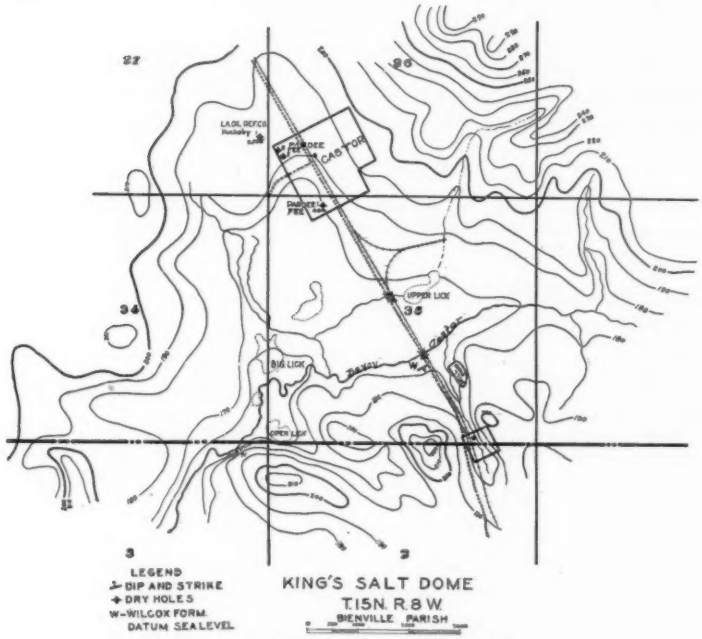


FIG. 13.—Topographic map of King's salt dome

An outcrop of limestone is reported in the bed of Bayou Castor, near the center of the SW. $\frac{1}{4}$ Sec. 35, T. 15 N., R. 8 W. Hilgard reports an outcrop of soft, fossiliferous, aluminous limestone, similar to the "rotten limestone" Mississippi, in the bed of Bayou Castor, and probably refers to the same outcrop which has since become covered.

Cretaceous beds penetrated in shallow brine wells sunk on the salt licks located on the outer margin of the central basin, together with the reported outcrop in Bayou Castor, indicate that Cretaceous beds of Marlbrook and younger age are present around the salt

core but are generally concealed by the inwash of sand from the surrounding high hills.

UNDERGROUND GEOLOGY

Fragments of gray fossiliferous limestone collected by Veatch from the wall of King's old well contained the following species: *Exogyra costata, Lima pelagica, Anomia, Gryphaea vesicularis* var., *Turritella triliva, Liopistha protexta*(?).

A water well dug at Neal's store, just across the street from the railway station at Castor, showed the following section:

WELL SECTION, NEAL'S STORE[1]

	Feet
1. Yellow sandy clay mottled with white. Contains a few quartz pebbles	17
2. Very dark gray, sandy, laminated clay with *Ostrea larva* and *Ostrea* sp	4

The fossils obtained from these wells are of Upper Cretaceous age and probably should be referred to the Marlbrook formation.

Pardee Fee No. 1 found cap rock from 161 to 192 feet, and rock salt from 192 to the bottom of the hole at 404 feet. Pardee No. 3 was abandoned in the cap rock at a depth of 1,413 feet. As drill cuttings and cores are not available from these wells, only tentative correlations can be established. The Louisiana Oil Refining Corporation—Huckaby No. 1—started in the Midway formation and was abandoned in the cap rock at a depth of 2,232 feet. This well had a complete section, as shown in Figure 14.

The cap rock, so far as can be determined from the wells drilled to date, is only about 50 feet thick. It is similar in appearance to the cap rock cropping out at Winnfield, but is anhydrite and gypsum instead of calcite.

STRUCTURE

King's salt dome (Fig. 14) consists of a central salt core one-half to three-quarters of a mile in diameter, surmounted by a cap rock 50 or more feet in diameter. The Cretaceous rocks were sharply flexed and pierced by the intrusion of the salt core. The truncated edges of these sharply flexed beds, now generally covered by alluvium, are present around the periphery of the salt core. The

[1] Data from A. C. Veatch.

Marlbrook, present at the surface on this dome, normally lies at a depth of 1,900 to 2,000 feet below the surface. The maximum vertical relief, therefore, is not less than 2,000 feet.

RAYBURN'S SALT DOME

LOCATION AND HISTORY

Rayburn's salt dome is located in the southeastern part of Bienville Parish. The center of the dome is in Sec. 35, T. 15 N., R. 5 W. It is 20 miles south of Arcadia dome and 5 miles northeast of Prothro dome.

The earliest record of salt-making at this locality dates from the early forties, when a Mr. Faust, owner of the land, commenced operation on a small scale. This work continued until the Civil War, when the federal blockade of the southern ports became effective and caused the salt to have a greatly enhanced value. In 1862 salt-making on a large scale commenced. A rent of $37\frac{1}{2}$ cents per bushel was charged for the privilege of making salt and for the wood consumed. The receipts of the owner of the land at this rate are said to have amounted to $375 a day. This would give a daily production of about 1,000 bushels. Sampson Rayburn, who married a daughter of Faust, was placed in charge and collected the rent. It was in this way that the lick became known as Rayburn's.

At the close of the war the works were almost abandoned. Occasionally a small amount of salt was made for local consumption as late as 1877.

This locality was described by Hilgard,[1] in 1873, and by Lerch,[2] in 1893, who reported the occurrence of *Exogyra costata*, thus adding to the proof of the existence of Cretaceous rocks in Louisiana. Rayburn's was described by Harris and Veatch[3] in 1899, and an excellent topographic map of this locality is shown by Veatch[4] in his comprehensive report of 1902 describing this locality in detail.

[1] E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans, 1873.

[2] Otto Lerch, "A Preliminary Report upon the Hills of Louisiana South of the Vicksburg, Shreveport & Pacific Railroad," *Bull. Louisiana Experiment Station, Geol. and Agri.*, Part II (1893), pp. 72–73.

[3] G. D. Harris, and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899* (1900), pp. 52–55.

[4] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 71–75.

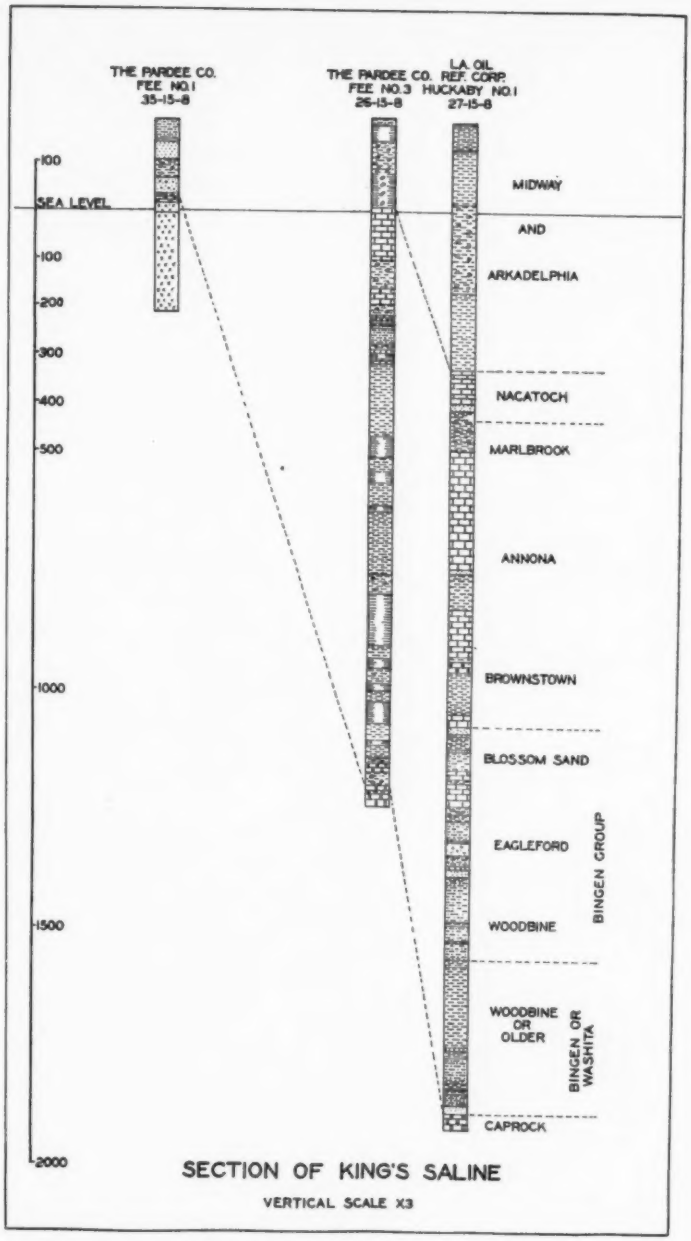


FIG. 14.—Well sections on King's salt dome

The old brine wells were shallow, usually 20–25 feet in depth. An attempt to develop this dome was made in 1910 by J. L. Dormon and associates, who drilled two wells, both located near the center of the saline. Both wells were abandoned in the cap rock, one at a depth of 37 feet and the other at a depth of 85 feet. In September, 1923, the Hodge-Hunt Lumber Company drilled their Fee No. 2, in Sec. 29, T. 15 N., R. 5 W., to a depth of 3,003 feet. In December, 1923, the same company drilled Fee No. 3, located near the center of Sec. 31, T. 15 N., R. 5 W. This well had cap rock from 85 to 115 feet and rock salt from 115 to 277 feet, at which depth it was abandoned.

TOPOGRAPHY

Rayburn's is a typical example of a salt dome with a central saline encircled by hills. The dome (Fig. 15) consists of a central saline 2,000 feet in length and 1,500 feet in width at the widest place. It is a slightly swampy area with an altitude of 180 feet above sea-level. The southern end is somewhat lower and, during heavy rains, is flooded to a depth of two or three feet. Gently sloping hills, which at a distance of 4,000 to 5,000 feet away rise 60–100 feet above the saline, encircle it.

Radial streams fed by surface water and by springs empty into the saline from all directions. A part of this water flows over the surface to form Faust Creek at the south end of the saline, but a large part sinks into the sand and gravel overlying the cap rock, and finally finds its way into Faust Creek through underground channels.

The saline represents the highest part of the uplift, and closely outlines the extent of the salt core.

SURFACE GEOLOGY

Rayburn's salt dome is in the outcrop of the Sparta sand, but older rocks, including the Blossom sand of Cretaceous age, crop out at the surface on the edges of the central saline.

CRETACEOUS FORMATIONS

Blossom sand.—A small outcrop of Blossom sand appears in the old road near the SW. cor., SW. ¼ of NE. ¼ of Sec. 30, T. 15 N., R. 5 W. It is poorly exposed and deeply weathered, having the appear-

ance of ferruginous sand. When freshly broken it is a greenish-gray calcareous sandstone, identical with the Blossom outcrop on Prothro dome. The several fossils collected from this outcrop definitely establish the correlation.

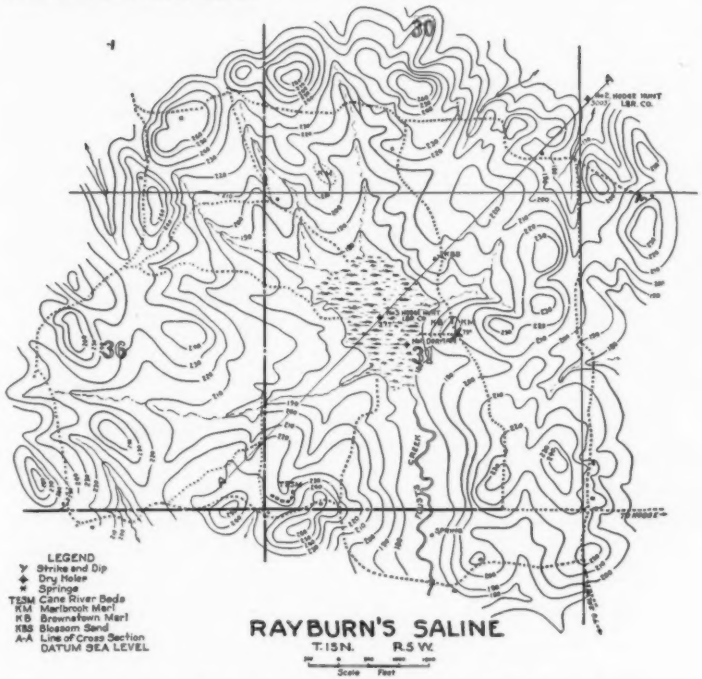


FIG. 15.—Topographic map of Rayburn's salt dome showing characteristic central saline encircled by hills.

Chalk and marl.—The Marlbrook formation and probably somewhat older beds crop out in two localities lying, respectively, north and east of the central saline. The outcrop on the east side shows about 500 feet of beds, consisting of fine-grained white chalk at the top and grayish-green to yellow-colored calcareous clay marls at the base. A thin bed of fossiliferous, sandy limestone is present at the base of the chalk. The chalk is highly fractured, and the fractures are often filled with calcite. The beds strike N. 30 E., and dip

75 degrees SE. The outcrop on the north is similar to that just described, except that a relatively greater thickness of clays and a less thickness of chalk is exposed. The beds dip about 65 degrees NE.

The calcite veins cutting the chalk strike N. 60 W. Fragments of celestite and barite are scattered over the surface around these outcrops, and a vein of barite, lying just above the chalk on the east side of the saline, has been traced about 150 feet, striking N. 10 E.

Chalk is reported from shallow wells on the west side of the saline, but the writer has had no opportunity to confirm this report.

The topography and the character of the residual soil indicate that the Cretaceous beds just described form a belt around the salt core. The Nacatoch and Arkadelphia formations have not been recognized on this dome, but are undoubtedly present under the residual sand from the encircling hills.

TERTIARY FORMATIONS

The older Tertiary, comprising the Midway and Wilcox formations and the Cane River beds of the Lower Claiborne group, are not well exposed on this dome, owing to the mantle of sand washed in from the encircling hills. Beds of Midway age were not recognized. The Wilcox crops out in several places, but is best exposed around Lowe's house and in the field east of the house in the SW. ¼ Sec. 30, T. 15 N., R. 5 W. It consists of light-colored and red ferruginous sand and sandy clays. The glauconitic clays, which are poorly exposed in the NE. ¼ Sec. 36, T. 15 N., R. 5 W., unquestionably belong in the Cane River beds, as do the fossiliferous, calcareous concretions found on the inner slope of the encircling hills in the SW. cor., Sec. 31, T. 15 N., R. 5 W. Sparta sand is well exposed in the hills and in the surrounding country.

UNDERGROUND GEOLOGY

The old brine wells sunk on Rayburn's saline found cap rock after passing through a few feet of alluvium. The cap rock in the Hodge-Hunt Lumber Company—Fee No. 3 well—was 30 feet thick. The maximum thickness is probably somewhat greater. It consists chiefly of white- and gray-banded calcite rock, but gypsum and anhydrite are found in the walls of the old brine wells. Hodge-Hunt

Lumber Company—Fee No. 2 well, located 5,000 feet northeast of Fee No. 3—had a normal section. It was abandoned in the upper part of the Bingen at a depth of 3,003 feet.

STRUCTURE

An ideal section of Rayburn's salt dome is shown in Figure 16. This section is generalized and does not take into consideration faulting, which usually accompanies the intrusion of the salt core. This dome is believed to represent the typical development of the interior salt domes of northern Louisiana. It shows the pluglike

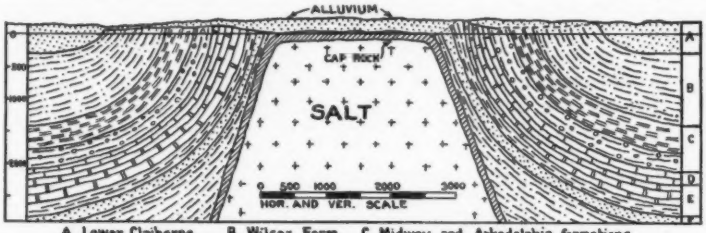


FIG. 16.—Cross-section of Rayburn's salt dome

form of the salt core, the piercing of the beds as the salt moved upward, the sharp flexing of the beds around the salt core, the deep truncation of the core, and the localization of the uplift.

PRICE'S SALT DOME

LOCATION AND HISTORY

Price's salt dome is located in northwestern Winn Parish, 6 miles northeast of Drake's and 12 miles south of Rayburn's salt domes. The center of the uplift is in Sec. 30, T. 13 N., R. 5 W. This dome is most easily reached by road from the station of Calvin on the Louisiana & Arkansas Railroad.

The first recognition of the locality is found on Tanner's[1] map of Louisiana, where it is marked "Salt Lick." The exact date of the first attempt to make salt here is not known. John Walker moved to this part of the country in 1859 and found old wells on the licks. Price's salt dome shared with other salt domes a period of intense activity during the Civil War, but records to show the daily produc-

[1] N. S. Tanner, Map of Louisiana, Philadelphia, 1820.

tion for this period are not available. The last attempt to make salt on any considerable scale was made by a man named Bynum, in 1869.

Price's salt dome was described in detail by Veatch[1] in 1902.

The old brine wells are shallow, usually 10–20 feet in depth. The Vivian Oil Company drilled their Bodcau No. 1, located near the center of the NW. ¼, Sec. 25, T. 13 N., R. 5 W., in 1916. This well was abandoned in the Blossom sand at a depth of 2,134 feet.

TOPOGRAPHY

The dominant topographic features of Price's salt dome (Fig. 17) is the central hill, Lick Hill, which is completely separated from the surrounding hill lands by the barren licks, or salines, encircling its base. The rolling, hilly lands on the west and southwest sides of the central hill reach an elevation of 180 feet above sea-level, or 95 feet above the salines and the bottom lands. On the north the hills are lower, and cut by the broad valley of Cypress Bayou. On the east side a narrow ridge, broken in three places by stream channels, separates the saline from the Dugdemona bottoms. The general features of Lick Hill are shown in Figure 17, but the several minor topographic features, notably the small holes, like sink holes, which are scattered over the hill, are but imperfectly represented. The largest of these holes is just south of the apex of the hill. It is about 75 feet in diameter and 20 feet deep.

The salt-dome region is drained by Dugdemona Bayou, which flows in a general southward direction on the east side of the dome. The salt dome proper is drained on the north by Cypress Bayou and on the south by Powder Spring Branch. Small radial streams rising on the flanks of the encircling hills on the west and south sides of the dome empty into the salines to form a circular drainage system around the base of Lick Hill.

SURFACE GEOLOGY

The hills encircling the dome are composed of light-colored and red sands and clays. Thin partings of ferruginous sandstone are not uncommon, and some clay ironstone occurs. The beds are generally

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 64–70.

massive, but in some places are poorly bedded. The upper parts of the hills are covered with fine gray sand, which generally conceals the structure of the underlying beds. The central hill is covered

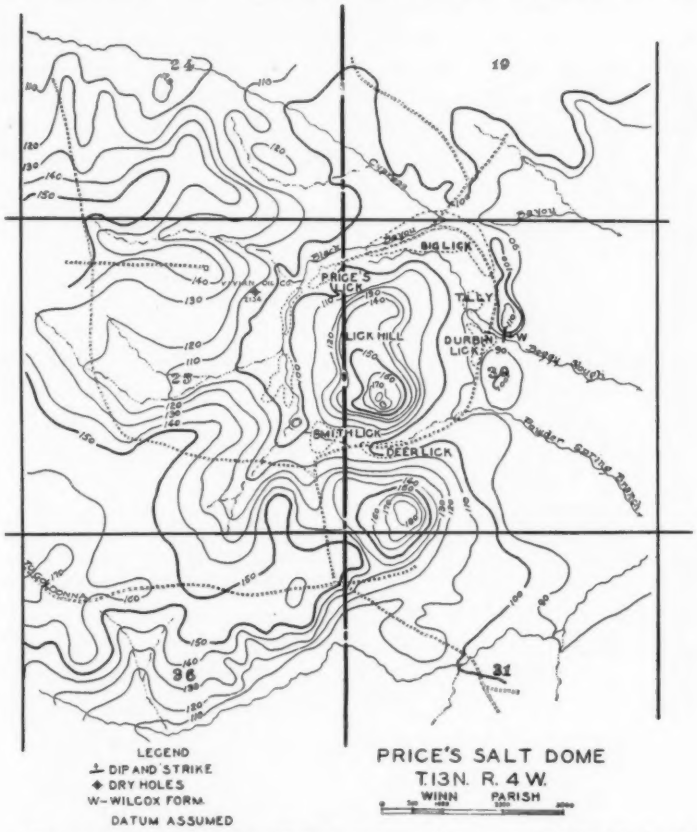


FIG. 17.—Topographic map of Price's salt dome, showing central hill with circular drainage system around the base.

with red sand, apparently residual, as several test pits show it to be underlain by light-colored sand and sandy clay, essentially similar to that exposed on the inner flanks of the encircling hills. A single outcrop of hard, light-gray, calcareous sandstone, containing leaf

impressions and small particles of lignite, occurs on the inner slope of the low ridge facing Lick Hill on the east. It is almost identical in character and appearance with the outcrop at Rock Bluff, on Drake's salt dome. This outcrop is assigned to the Wilcox formation. It is small and poorly exposed; the strike appears to be north-south, and the dip is to the east. The beds outcropping on the inner flank of the encircling hills resemble the Wilcox formation, and the beds exposed higher on the hills and in the surrounding hill lands are typical Sparta sand. If this correlation is correct the marine, glauconitic, Cane River beds should outcrop in the hills, but the writer was unable to find them. The inwash of sand from the hills could easily have concealed them.

UNDERGROUND GEOLOGY

The shallow brine wells sunk on the salines, usually 10 to 20 feet in depth, penetrated silt, sand, and clay. Veatch[1] gives the following well section:

WELL SECTION, TILLY LICK

	Feet
1. Light sandy clay	2
2. Yellow clay mottled with red	5
3. Very dark blue clay	3

The dump heaps show fragments of calcareous sandstone similar to the outcrop previously described, as well as fragments of hard blue limestone resembling the calcareous bowlders of the Wilcox formation. Hilgard[2] reports the finding of vivianite, a mineral commonly associated with salt-dome cap rock. The well drilled on the west side of the dome by the Vivian Oil Company showed the following log:

LOG OF THE VIVIAN OIL COMPANY—BODCAU NO. 1, IN SEC. 25, T 13 N., R 5 W.

	Depth (Feet)
Lignite	59
Fine packed sand and bowlders	84
Soft gumbo	85
Good fresh water show, water sand	104
Hard gumbo	110

[1] *Op. cit.*, p. 68.

[2] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana* (New Orleans, 1873), p. 31.

	Depth (Feet)
Packed sand	122
Lignite, harder	134
Packed sand	146
Shale	149
Dolomite	166
Sandy shale	173
Dolomite	175
Blue flint rock	179
Sandy shale, packed	253
Rock, gas show	296
Packed sand	314
Fresh water sand	336
Lignite	342
Sandy shale	389
Mucky shale	428
Rock	431
Soft gumbo and bowlders	454
Hard packed sand	483
Shale and bowlders	506
Shale and bowlders	510
Packed sand	519
Soft gumbo	558
Rock with pyrite	560
Shale	570
Sandy shale and bowlders	594
Rock and pyrite	595
Soft gumbo	605
Rock	614
Sandy shale and bowlders	646
Rock and pyrite	647
Sandy shale	657
Rock	671
Coarse packed sand	675
Rock and pyrite	679
Sandy shale	698
Packed sand	733
Soft rock	737
Soft shale and gumbo	773
Gumbo, shale, bowlders, show of gas	804
Rock and pyrite, broken	814
Shale and bowlders	817
Salt water sand	823
Rock and pyrite	826
Sand rock with salt water	849
Lignite	857
Sandy shale	877
Rock and pyrite	887

	Depth (Feet)
Soft gumbo	899
Lignite	905
Rock and pyrite, soft and porous in places	913
Rock and pyrite, porous	917
Rock and pyrite	931
White sand and bowlders	947
Soft shale and bowlders	967
Hard gumbo	978
Rock and pyrite	979
Hard shale and bowlders	1,009
Rock and pyrite	1,013
Hard shale and bowlders	1,033
Rock and pyrite	1,035
Rock and pyrite	1,060
Hard shale	1,077
Rock and pyrite	1,081
Lignite	1,255
Hard shale and bowlders	1,494
Hard gumbo	1,505
Soft white rock	1,511
Gumbo	1,539
Hard shale	1,554
Hard gumbo	1,689
Rock	1,693
Hard shale	1,696
Chalky rock	1,699
Chalky rock, hard	1,946
Gumbo	1,953
Hard shale	1,971
Hard gumbo	1,988
Rock	2,029
Sand rock	2,091
Gumbo	2,104
Sand rock	2,134

Drill cuttings and cores are not available from this well, but an examination of the cuttings in the slush pit and around the casing head shows many fragments of chalk, *Inoceramus* prisms, and dark-colored shale, proving beyond reasonable doubt that the chalk was penetrated in this well. The sand recorded in the log, from 2,030 feet to the bottom of the hole at 2,134 feet, is probably the Blossom sand (Upper Bingen).

The sink holes on Lick Hill indicate a bed of soluble material beneath the surface sand. Test pits sunk to a depth of 40 feet found only sand and sandy clay, but that cap rock and rock salt underlie it at a moderate depth would seem a reasonable presumption.

STRUCTURE

The massive or poorly bedded sand and sandy clays exposed around this dome give no clues to the dips of these beds. The Blossom sand, found at a depth of 2,030 feet in the Vivian Oil Company's Bodcau No. 1, normally lies at a depth of 3,100–3,200 feet, indicating an uplift of more than 1,000 feet. As this well was drilled on the flank, the total uplift probably is considerably greater.

The salt licks or salines encircling the central hill perhaps closely outline the extent of the cap rock.

DRAKE'S SALT DOME

LOCATION AND HISTORY

Drake's salt dome is located in Winn and Natchitoches parishes. The center of the uplift is in Secs. 20 and 21, T. 12 N., R. 5 W. It is 6 miles southwest of Price's and 12 miles northwest of Winnfield salt domes. The town of Goldonna is one mile west of the dome.

According to the early settlers, the Indians made most of their salt at the Little Lick, and this statement is substantiated by the large accumulation of pot-shreds present about this lick. The salt at this locality was mentioned in the *Journal* of M. de Bienville,[1] of March 22, 1700, and many other references to this locality are found in the accounts of the early history of northern Louisiana. The exact date when white men first made use of the salt springs is uncertain, but one of the first accounts was given by John Sibley,[2] in a letter to General Dearborn, dated Natchitoches, April 10, 1805.

The local demand so increased that in the early forties a certain Reuben Drake, who was then in possession and whose name the locality yet retains, attempted to obtain stronger brine by deep boring. Eight wells were drilled, one, near the milldam on the north side of the dome, to a depth of 1,011 feet. The others appear to have been from 100 to 200 feet deep. Artesian brine was found in each. In the deep well the pressure was sufficient to lift the water into a tank 35 feet above the top of the pipe. As the brine from this well was much weaker than that obtained from the shallower wells, it was not used to any extent. At the present time this well is flowing a small amount of salty water.

[1] Grace King, *Sieur de Bienville* (New York, 1892), pp. 100–102.

[2] John Sibley, "Louisiana: An Account of the Red River and Country Adjacent," *American Register*, Vol. 4, pp. 49–67.

The property passed into the possession of M. J. C. Wells, who commenced to make salt in 1854. He used two wells, one on Little Lick and the other on Upper Lick. During the salt season he made from 30 to 40 bushels daily.

With the outbreak of the Civil War salt operations on a large scale commenced, and continued to the end of the war. No records of the production are available, but it was probably second only to that of Bistineau. At the close of the war, operations on any considerable scale ceased.

Drake's salt dome was described in detail in 1902 by Veatch,[1] who gives a very complete history of this dome.

The first deep well, Drake's artesian well, was drilled in 1864

TABLE V

WELLS DRILLED ON DRAKE'S SALT DOME

Company	Farm	Location	Total Depth (Feet)	Year	Salt (Feet)
Reuben Drake.....	Old Artesian Well	21, 12 N., 5 W,	1,011	1864–65	No
Savage Brothers....	Test Well No. 1	21, 12 N., 5 W.	2,262	1906	900
Savage Brothers.....	Test Well No. 2	21, 12 N., 5 W.	1,510	1907	No

and 1865, and Savage Brothers drilled two wells in 1906 and 1907 to depths of 2,262 and 1,510 feet, respectively (Table V).

TOPOGRAPHY

The topography of Drake's salt dome (Fig. 18) is of the type common to most of the domes of this region. The central basin is about one mile in diameter, and, except for a low ridge on the west side, it is a low, swampy area which, during high water, is entirely covered with water. The barren salt licks are distributed around the margin of the basin. The salt licks are encircled by gently rolling hill land, 30 to 40 feet higher than the salines.

Hickory Nut Ridge, on the southeast side of the dome, rises 100 feet above the general level of the surrounding country, and, together with the central saline area, is the outstanding topographic feature of this locality.

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 51–64.

The salt dome is drained by Saline Bayou, flowing southward through the center of the dome. Cole Branch on the east and Malladoe Branch on the west side are the most important tributaries.

SURFACE GEOLOGY

The hills surrounding Drake's salt dome are composed of Sparta sand, which is normally at the surface here. Wilcox beds outcrop

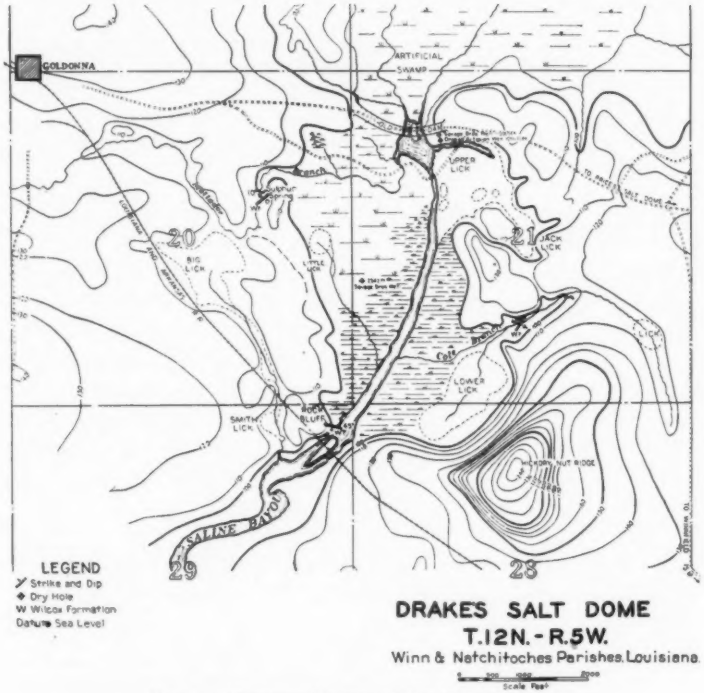


FIG. 18.—Topographic map of Drake's salt dome

on Malladoe Branch, Cole Branch, and at Rock Bluff on Saline Bayou. Rocks of Cretaceous age are not known at the surface in this locality.

The most important outcrop is at Rock Bluff, in the NE. cor., Sec. 29, T. 12 N., R. 5 W., where a gray, granular, calcareous sandstone containing leaf impressions, thin streaks of lignite, calcite in

thin veins, and nodules of pyrite is exposed. The length of the outcrop is about 75 feet, and about 40 feet of beds are exposed at low water. Lithologically it is similar to the calcareous sandstone at Coochie Brake. The beds strike N. 80 W., and dip 45 degrees SW. A similar, but smaller, outcrop on Cole Branch strikes N. 56 E., and dips 40 degrees SE. On Malladoe Branch, near the center of the NE. $\frac{1}{4}$ of Sec. 20, T. 12 N., R. 5 W., is a small outcrop of gray,

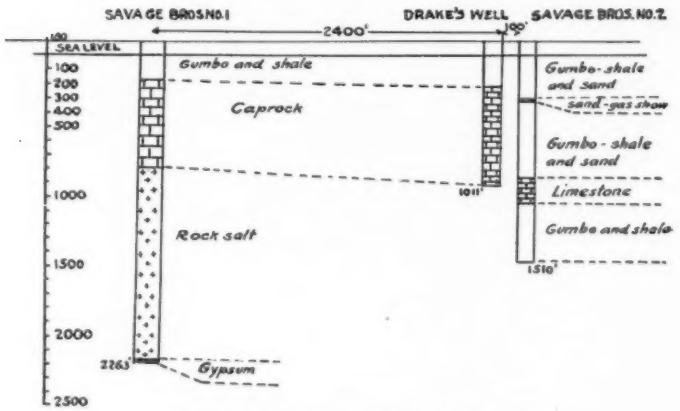


FIG. 19.—Well sections on Drake's salt dome

laminated sandy clay, dipping 10 degrees NW. These outcrops are assigned to the Wilcox formation, but, in the absence of fossils, their exact age is not definitely established.

UNDERGROUND GEOLOGY

Graphic sections of the wells drilled on Drake's salt dome are shown in Figure 19. Drake's artesian well, drilled in 1864 and 1865, was reported by Hilgard,[1] and the following partial section is given by Veatch:[2]

[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana*, New Orleans, 1873.

[2] A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey, Prof. Paper 46* (1906), p. 300.

PARTIAL SECTION OF TEST WELL AT DRAKE'S SALT WORKS, SEC. 21, T. 12 N., R 5 W.

	Feet
1. Yellow sand clay	0– 5
2. White sand	5– 42
3. Cypress log, very much decayed and charred on each side	42– 43
4. Soft sand and streaks of clay of various colors	43–318
5. Very porous crystalline limestone; crevices filled with white and yellow calcite crystals	318–475
6. According to Hilgard, cap rock continued to bottom of hole, at	1,011

Savage Brothers' Test Well No. 1, located in the center of the saline, had sand, gumbo, and shale to 290 feet, cap rock from 290 to 900 feet, and rock salt from 900 to 2,260 feet. It was abandoned in hard gypsum at a depth of 2,260 feet. Savage Brothers' Test Well No. 2, located about 100 feet from Drake's well, had sand, gumbo, and shale to 955 feet, limestone from 955 to 1,135 feet, and gumbo and shale from 1,135 feet to the bottom of the hole at 1,510 feet. As neither drill cuttings nor cores are available from this well it is not possible to establish the correlation of the beds penetrated, but the 180 feet of limestone found is probably of Nacatoch or Marlbrook age. Savage Brothers' Well No. 1 had 610 feet of calcite cap rock, identical with the cap rock which outcrops on Winnfield Quarry dome. This well was abandoned after drilling hard gypsum from 2,260 to 2,263 feet.

STRUCTURE

Drake's salt dome consists of a central salt mass, roughly circular in form, and $\frac{1}{2}$–$3\frac{1}{4}$ miles in diameter. The salt mass is overlain by calcite cap rock 600 feet or more in thickness on top of the dome, and presumably decreasing in thickness down the sides of the salt core. The lowering of the salt core, brought about by the removal of salt in solution, has caused the central basin, which is a conspicuous feature of the topography of this dome. As this area was lowered it was partially filled with alluvium, washed in from the surrounding hill lands, which has covered the truncated edges of the older rocks tilted up around the salt core. The Wilcox beds, exposed at Rock Bluff and other places, dip away from the center of the dome at the rate of 10 to 45 degrees. The probable structure of the salt core and

cap rock and the attitude of the sedimentary strata are shown in Figure 20. The total vertical uplift of this dome cannot be determined, but, judging from stratigraphic evidence, it is estimated to be not less than 2,000 feet.

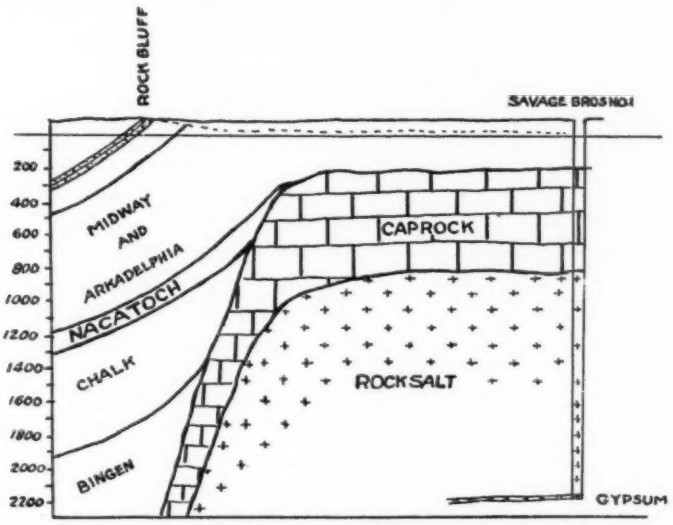


FIG. 20.—Section A-A[1] showing probable structure Drakes salt dome

THE WINNFIELD SALT DOME

LOCATION AND HISTORY

Winnfield salt dome is 4 miles west of the town of Winnfield, Winn Parish. The center of the dome is in Secs. 19 and 30, T. 11 N., R. 3 W. It is 8 miles northwest of Cedar Creek and 12 miles southwest of Drake's salt dome.

The Winnfield dome has been known for many years, and it is reported that limestone was quarried and burned for lime at this place long before the Civil War. The locality was described by Hilgard[1] in 1873. Harris and Veatch[2] described the geology in 1899,

[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana*, New Orleans, 1873.

[2] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899*, Part V (1900), pp. 56–59.

and pointed out the quaquaversal structure associated with this and other salt domes of northern Louisiana. Harris,[1] in 1907, described this area in more detail.

At the present time limestone is quarried, and a crushing plant with a daily capacity of about 1,000 tons is in operation. J. T. Lyons, Jr., of New Orleans, Louisiana, estimates that a million tons of rock have been removed to date.

Drilling for oil and gas began in 1914, when the Tampico Oil Company drilled to a depth of 2,112 feet in Sec. 19, T. 11 N., R. 3 W., on the north side of the dome. The following list (Table VI) shows the wells drilled on and around this dome.

TABLE VI

WELLS DRILLED ON WINNFIELD SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
Tampico Oil Co....	Southern Mineral Co.	1	19, 11 N., 3 W.	2,112	1914	No
Cady Petroleum Co.	Southern Mineral Co.	1	19, 11 N., 3 W.	1,100	1920	999
Cady Petroleum Co.	Southern Mineral Co.	2	24, 11 N. 4 W.	1,246	1920	No
Gulf Refining Co...	Southern Mineral Co.	1	30, 11 N., 3 W.	4,021	1921	No

The Tampico Oil Company and the Gulf Refining Company wells found cap-rock material at several different depths, but salt was not encountered.

TOPOGRAPHY

The altitude of the bottom land along Bayou Sonnett, on the north side of the dome, is 140 feet above sea-level, and that of the highest hills in the locality is 260 feet, giving a total relief of 120 feet. The central part of the dome, represented by the outcrop of calcite cap rock, is slightly basin-shaped, being 60–80 feet lower than the rim of hills encircling it on all but the north side. This rim of hills, sloping steeply toward the center of the dome, although no higher than the hills farther away from the center of the uplift, is nevertheless a marked feature of the topography of the dome (Fig. 21). The hills owe their presence to a capping of hard, ferruginous sandstone in the St. Maurice beds.

The regional draining is through Bayou Sonnett, which rises

[1] G. D. Harris, "Notes on the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 5 (1907).

several miles to the northwest. It flows in a general northeasterly direction until near the west side of the dome, where it follows the periphery of the uplift to the center of Section 19, where it again changes its direction to northeast and empties into Port Luce Creek. Rocky Branch, which rises near the center of the SW. $\frac{1}{4}$ of Sec. 30,

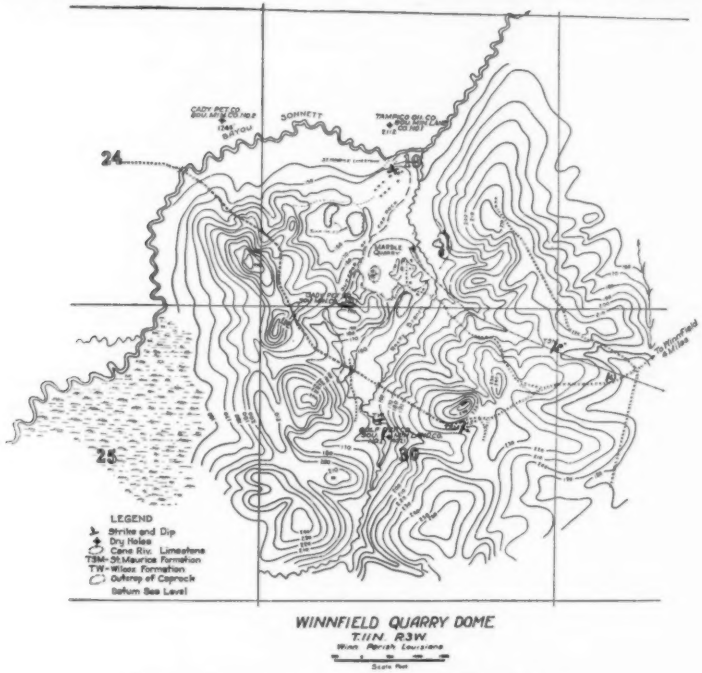


FIG. 21.—Topographic map of Winnfield Quarry dome

drains the salt dome. It flows northeast, along the cap rock outcrop, and empties into Bayou Sonnett near the center of Sec. 19, T. 11 N., R. 3 W.

An interesting feature is present in the low, marshy area lying between the encircling hills and Bayou Sonnett on the southwest side of the dome. This area is densely covered with trees, and its true nature has not been ascertained, but it is believed to represent an old course of the bayou in an earlier attempt to encircle the dome on the south side.

Many springs are present on the inner flanks of the encircling hills.

SURFACE GEOLOGY

Winnfield salt dome lies a short distance south of the contact between the St. Maurice beds and the Yegua formation. The encircling inner rim of hills is composed of sand, clay, and ferruginous sandstone belonging to the St. Maurice beds and the Sparta sand of the Claiborne group. The Cane River beds are represented by a small outcrop on the north side of the dome, and the Wilcox formation is recognized in two small isolated exposures. The outstanding feature of the dome is the exposure of the calcite cap rock over a considerable area in the center of the uplift. Cretaceous rocks have not been recognized in this locality.

Cap rock.—The highest part of the dome is represented by an outcrop of calcite cap rock, covering an area of about 120 acres, in Secs. 19 and 30, T. 11 N., R. 3 W. That this limestone is more extensive than the surface outcrop is indicated by the sink holes present on the east and west sides of the outcrop. In the quarry face, 70 feet of limestone is exposed, but its total thickness is about 1,000 feet, as shown by the following well record:

DESCRIPTION OF SAMPLES FROM CADY PETROLEUM COMPANY— SOUTHERN MINERAL COMPANY NO. 1, SEC. 19, T. 11 N., R. 3 W.

	Depth (Feet)
Limestone, white and bluish-gray, many small pockets of calcite crystals evident	125
Very small fragments of grayish-blue banded marble	236
A very fine white water sand	300–303
Marble, grayish-blue; fine to rather coarse material	314
Gray to dark marble	320
Marble, white and blue	326
Fine, white sand	326–334
White and blue-banded marble, predominantly white in color. One fragment contained a very small pocket of sulphur, burning readily and giving characteristic fumes	334–367
White to gray and blue-banded marble	367–386
White and blue-banded marble	391–409
Blue-banded marble, together with much fine to medium-textured white to colorless sand	409–419
Gray and blue-banded marble; some pieces of white calcite	432–436
Very fine, white, calcareous sand	436–438
White and blue-banded marble	438–999

The cap rock from the dome is described by M. I. Goldman, of the U. S. Geological Survey, as follows:

Hand specimen.—A very coarsely crystalline white limestone with thin fine-grained gray bands, partly very continuous and partly very twisted, shattered, faulted, or discontinuous, as if the material of the rock had been rearranged with some displacement. Full of cavities of varying size up to one-half inch, elongated parallel to the bedding, into which terminated crystals project Orange-brown impurities along the walls of the cavities.

Thin section.—Very large calcite crystals which, at extinction, have a mottled and flecked appearance; the flecks have a distinct fibrous appearance, with the orientation in two directions. By immersion of crushed material of the rock in a liquid of index equal to that of calcite these are found to be not inclusions, but planes developed in the rock presumably by pressure. Inclusions, on the contrary, are very scarce, and consist mostly of small dirty granules, probably argillaceous. At one point a small fragment of what appeared to be anhydrite was seen lying between calcite grains. The black bands are found to consist of fine-grained matter of argillaceous texture, disseminated in and around the calcite crystals apparently with little regard to present crystal boundaries. The crystals in these bands are generally somewhat finer, but the bands are not sharply defined, either in form or character.

Residue insoluble in acid.—Treatment with cold dilute hydrochloric acid leaves a small residue (perhaps ½ per cent) which is found to consist mostly of barite, with perhaps a little anhydrite and celestite. The majority of the grains are full of small black inclusions which suggest that they come mainly from the gray bands. Numerous very perfect, doubly terminated small (about 0.05 to 0.1 mm.) quartz crystals occur, evidently formed in place.

N. Bawles, of Winnfield, Louisiana, has furnished the following analysis of the cap rock:

Quantitative Analysis	Percentage	Combining Results	Percentage
Silica as SiO_2	1.25	Calcium carbonate ($CaCo_3$)	85.33
Iron and Alumina	1.50	Calcium oxide (CaO)	9.18
Calcium as CaO	56.95	Silica (SiO_2)	1.25
Magnesium as MgL.P_2O	1.20	Iron and Alumina (Fe and Al)	1.50
Sulphates	0.82	Magnesium (Mg)	1.20
Loss on heating (carbon dioxide	35.00	Sulphates	0.82

Loss at 120 degrees very small

The fine exposure of the unweathered cap rock in the 70-foot quarry face gives a good idea of the irregularity of the blue-gray

banding which changes laterally, in a distance of a few feet, from the width of pencil marks to bands more than one inch in width. The highly fractured condition of this limestone mass is also well illustrated here.

EOCENE FORMATIONS

Wilcox formation.—This formation is not well exposed, but is probably present in many places around the periphery of the cap rock, where it is generally concealed by the inwash of sand from the surrounding hills. Two outcrops, one on the north side and one on the south side of the cap rock outcrop, are correlated with the Wilcox formation. The outcrop on the north side lies under the Claiborne limestone, where 30 to 40 feet of laminated, chocolate-colored and brown lignitic clay, striking about N. 80 E. and dipping NW., is assigned to the Wilcox formation. It contains a number of species of fossil plants. The other outcrop is in the bank of Rocky Branch near the center of Sec. 30, T. 11 N., R. 3 W. It consists of finely laminated lignitic clay which apparently dips to the southeast.

Cane River beds.—The basal beds of the Claiborne group are represented by a small outcrop near the center of Sec. 19, T. 11 N., R. 3 W. It consists of light-colored, somewhat glauconitic, highly fossiliferous limestone and glauconitic marly clay. The length of the outcrop is about 300 feet, and about 30 feet of beds are exposed. The beds strike N. 30 E., and dip 30 to 40 degrees NW.

Sparta sand.—The light-colored sands and sandy clays that appear on the inner flank of the hills encircling the cap rock outcrop belong to the Sparta-sand member of the Lower Claiborne. They are particularly well exposed in the old St. Maurice–Winnfield road, on both sides of Rodly Branch, in Sec. 30, T. 11 N., R. 3 W.

St. Maurice beds.—These beds, consisting of thin glauconite sand and marl beds interbedded with light-colored sand and sandy clay, containing a considerable amount of ferruginous sandstone, outcrop in the upper part of the encircling hills. They are well exposed along the quarry railroad and in the St. Maurice–Winnfield road. Dips of 10 to 15 degrees are observed.

Yegua formation.—The light-colored sand and lignite clays which make up this formation are well exposed in the area surrounding the dome. Dips of 1 to 3 degrees are noted.

UNDERGROUND GEOLOGY

Drill cuttings and cores are available from only two of the four wells drilled in this locality (Fig. 22). The Cady Petroleum Company—Southern Mineral Company No 1—started in the cap rock and continued in this material to 990 feet, where rock salt was encountered. It was abandoned in rock salt at a depth of 1,100 feet. The Gulf Refining Company—Southern Mineral Company No. 1—started in the Claiborne and at a depth of 4,012 feet was in the Arkadelphia formation of the Upper Cretaceous. Limestone and anhydrite were encountered at several depths in this well. A core from 2,020 feet consisted of gray anhydrite showing a dip of 70 degrees. Sandy lime is recorded at various depths, from 290 feet down to 1,800 feet. From the appearance of this material in the drill cuttings the lime is believed to be secondary. The Tampico Oil Company—Southern Mineral Company No. 1—records sand and shale from the surface to a depth of 1,185 feet, and considerable marble from 1,185 to 1,600 feet.

CEDAR CREEK SALT DOME

LOCATION AND HISTORY

Cedar Creek salt dome is located about three miles south of Winnfield, in Winn Parish. The center of the dome is in Secs. 30 and 31, T. 11 N., R. 2 W. It is seven miles southeast of Winnfield Quarry dome. The Winnfield-Alexandria highway crossed the central saline.

A small amount of salt was produced during the Civil War from a well located on the salt lick, on the west side of the dome, south of the highway. This locality was described by Hilgard,[1] and described in detail by Harris,[2] who gives a section of the supposed structure of the rocks underlying Cedar Lick.

Drilling for oil and gas commenced in 1903 and continued, with many interruptions, to 1917. Inadequate drilling equipment and the hard cap rock material prevented the wells drilled on the higher portion of the dome from reaching any considerable depth. Pardee

[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana* (New Orleans, 1873), p. 32.

[2] G. D. Harris, "Notes on the Winnfield Sheet," *Geol Survey of Louisiana, Report of 1907*, Bull. No. 7 (1907), pp. 10–14.

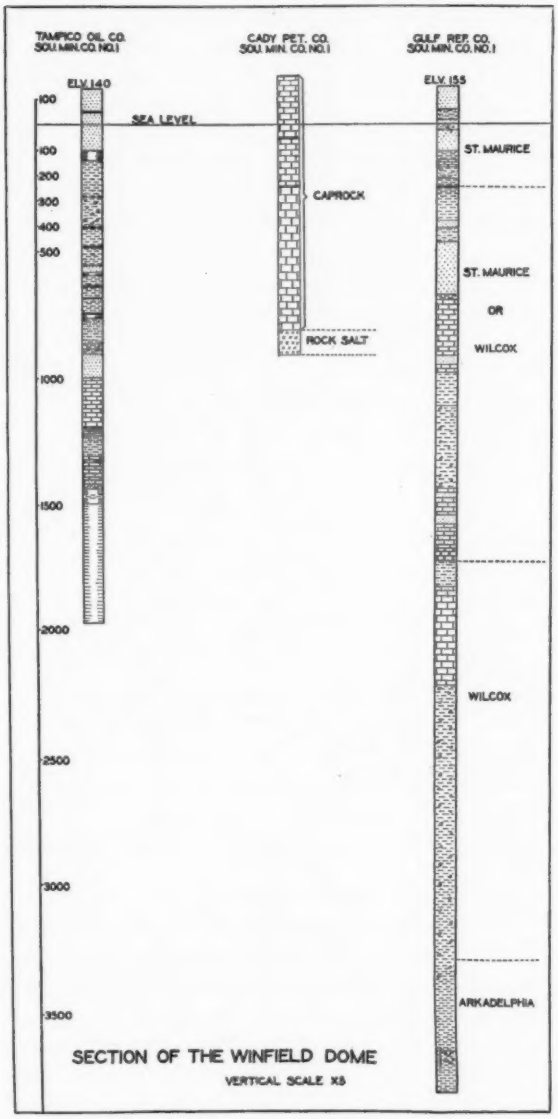


FIG. 22.—Well sections on Winnfield Quarry dome

No. 2 missed the cap rock and the salt and, as near as can be determined, was abandoned in the upper Bingen at 2,650 feet.

TOPOGRAPHY

The topography of Cedar Creek dome (Fig. 23) is very much like Drake's salt dome. It consists of a central saline basin over the salt mass, surrounded by a series of low hills. The central saline is a low, flat area about 6,000 feet long and 3,000 feet wide at the widest

TABLE VII

WELLS DRILLED ON CEDAR CREEK SALT DOME

Company	Farm	Number	Location	Year	Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
The Pardee Co.....	Fee	1	31, 11 N., 2 W.	1914	1,120	806	No
The Pardee Co.....	Fee	2	31, 11 N., 2 W.	1914	2,650	No	No
The Pardee Co.....	Fee	3	31, 11 N., 2 W.	1917	450	?	No
Pace *et al*.....	Pace	1	31, 11 N., 2 W.	1903–7	226–1,000	No	No
Pace *et al*.....	Pace	2	31, 11 N., 2 W.	1903–7	226–1,000	Yes	No
Winnfield Oil Co...	Butler	.....	31, 11 N., 2 W.	1903–7	226–1,000	Yes	No
Winnfield Oil Co...	Clifford	.....	31, 11 N., 2 W.	1903–7	226–1,000	?	No

point. It is covered with trees, except on the barren salt licks, or salines, grouped around its periphery. The elevation is 100 feet above sea-level, and the relief of the encircling hills, which merge with the gently rolling hill land of this area, is 50–70 feet.

The salt dome is drained by Cedar Creek, which meanders northward through the low area. Radial drainage converges in the central basin.

SURFACE GEOLOGY

Cedar Creek dome lies in the area of the Yegua formation, which is exposed in the upper portion of the encircling hills. St. Maurice beds crop out along the highway in the SW. $\frac{1}{4}$ of Sec. 30, T. 11 N., R. 2 W., and probably crop out in a belt encircling the central saline, where they have been covered by the inwash of sand from the surrounding hills. Older Tertiary and Cretaceous rocks are not known to crop out in this locality.

UNDERGROUND GEOLOGY

The underground geology is difficult to interpret from the meager data obtained from the wells drilled in this locality. The cap rock is found from 600 to 800 feet below the surface. It consists

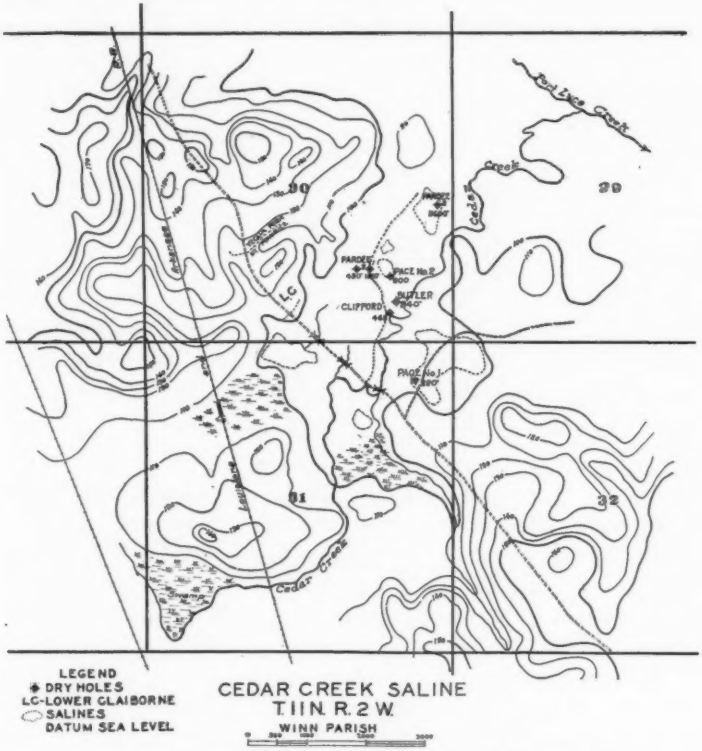


FIG. 23.—Topographic map of Cedar Creek salt dome

of white and gray banded calcite rock, similar to the cap rock at Winnfield, but containing more gray material and much more pyrite. The considerable amount of pyrite contained in this rock accounts for the hard drilling met with on this dome. More than 300 feet of cap rock were penetrated in Pardee No. 1 well, and its total thickness may be several hundred feet more. The age of the

600–800 feet of beds overlying the cap rock is not known, but from the driller's record appears to be, in part at least, of Cretaceous age.

Pardee No. 2 well, drilled about 1,500 feet northeast of the No. 1 well, appears to have had a normal section, finding neither cap rock nor rock salt. As the writer interprets this log (Fig. 24) it had chalk from 1,952 to 2,206 feet and the top of the Blossom sand at 2,247 feet. The record is incomplete from 2,310 feet to the bottom of the hole at 2,650 feet. If this correlation is correct, an uplift of more than 3,000 feet is indicated.

STRUCTURE

The cap rock penetrated in several of the wells drilled on this dome proves beyond reasonable doubt that the salt mass underlies it at some depth. The steepness of the dip around the cap rock is indicated by the logs of Pardee No. 1 and Pardee No. 2 wells (Fig. 24). The vertical uplift measured on the Blossom sand, normally about 4,500 to 5,000 feet below the surface in this region, but found at a depth of 2,247 feet, is about 2,700 feet. The total vertical uplift is probably somewhat greater.

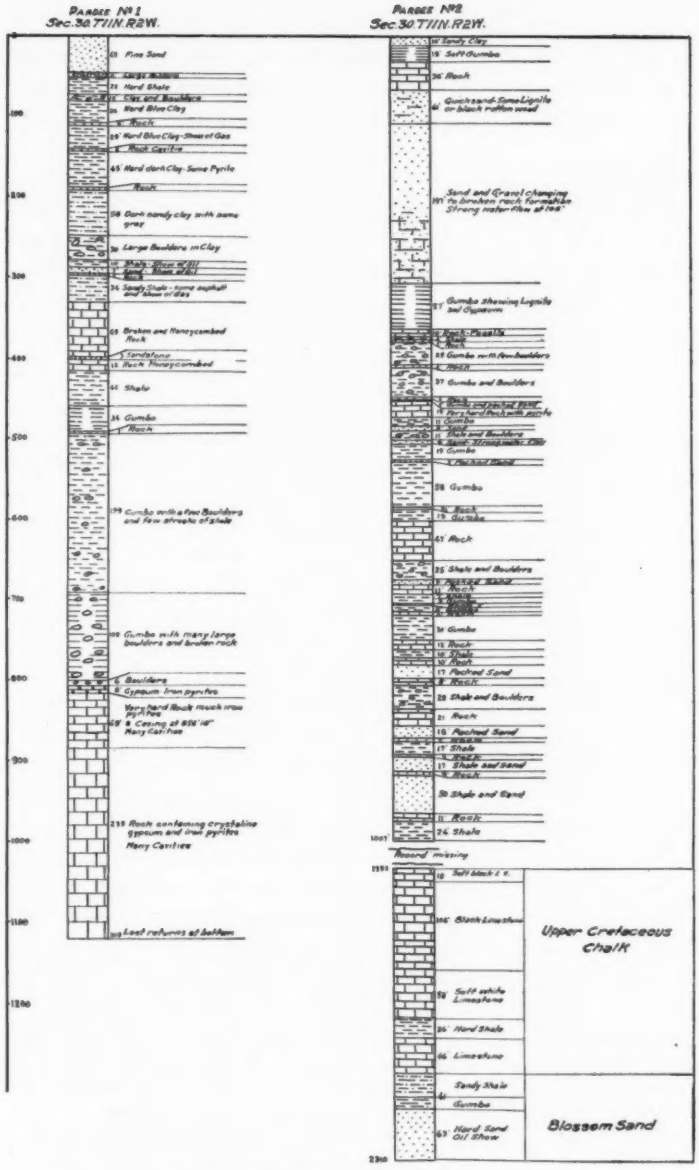
COOCHIE BRAKE

LOCATION AND HISTORY

Coochie Brake is located in the southwestern corner of Winn Parish, about 5 miles west of Atlanta and 15 miles southwest of Winnfield. The center of the brake, which is believed to coincide with the center of the uplift, is in Sec. 6, T. 9 N., R. 4 W. It is 8 miles southwest of Winnfield salt dome and 14 miles south of Drake's salt dome.

The limestone outcrop on the north side of Coochie Brake has been referred to by many of the early investigators of this region. Its chief interest to the layman seems to have been founded on the belief that precious minerals occurred in this locality. Harris and Veatch[1] believe that the glittering appearance of freshly broken pyrite nodules, which occur in this rock, have been at the bottom of the vast majority of statements concerning the mineral wealth of this part of Louisiana. Salt was not made at this locality, and it is therefore not so generally known as some of the other domes.

[1] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899* (1900), p. 60.



WELL SECTIONS CEDAR CREEK SALT DOME

FIG. 24.—Well sections on Cedar Creek salt dome

Harris and Veatch[1] described Coochie Brake in 1899, and Harris,[2] in 1907, amplified his previous statements concerning this locality. These investigators first interpreted Coochie Brake as a structural dome.

The Cady Petroleum Company drilled two wells in 1921, both located in Sec. 31, T. 10 N., R. 4 W. Edenborn No. 1 was junked at a depth of 1,912 feet, and Edenborn No. 2 was abandoned as a dry hole at a depth of 3,100 feet. Neither well reached cap rock or rock salt, but the information obtained from these wells substantiated the presence of an uplift comparable in magnitude to that of other salt domes in this region.

TOPOGRAPHY

Coochie Brake (Fig. 25) is a somewhat swampy area which, during the greater portion of the year, is covered with 2–4 feet of water. It is slightly more than one mile in diameter. The brake and the surrounding area, except on the north side, are densely covered with timber and underbrush. The altitude of the brake is about 150 feet above sea-level, and that of the highest hills encircling it on the north is 75–80 feet higher. The most conspicuous topographic feature of this locality is the calcareous sandstone outcrop which forms a prominent northeast-trending ridge in the SW. $\frac{1}{4}$ of Sec. 31, T. 10 N., R. 4 W. This ridge rises precipitously to a height of 65 feet above the level of the brake. Because of dense vegetation, the area to the south of the brake is practically unknown. Salt and sulphur waters and gas emanations are not known to occur, but it is possible that they may occur in the unexplored portion of the area.

The existence of a salt core underlying Coochie Brake is not proved, but the evidence of an uplift approaching some of the better-known domes in magnitude is reasonably conclusive. A comparison of the topography of Coochie Brake with that of Drake's salt dome, 14 miles to the north, is suggestive. Coochie Brake corresponds closely in outline and areal extent to the central saline area at Drake's, and the calcareous sandstone, dipping steeply away from the dome, is present in both localities and occupies the same posi-

[1] *Op. cit.*, pp. 59–61.

[2] G. D. Harris, "Notes on the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907.*

tion relative to the central low area. The rock in both places is essentially similar in character.

SURFACE GEOLOGY

The hills around Coochie Brake are composed of light-colored sands belonging to the Yegua formation of the Upper Claiborne.

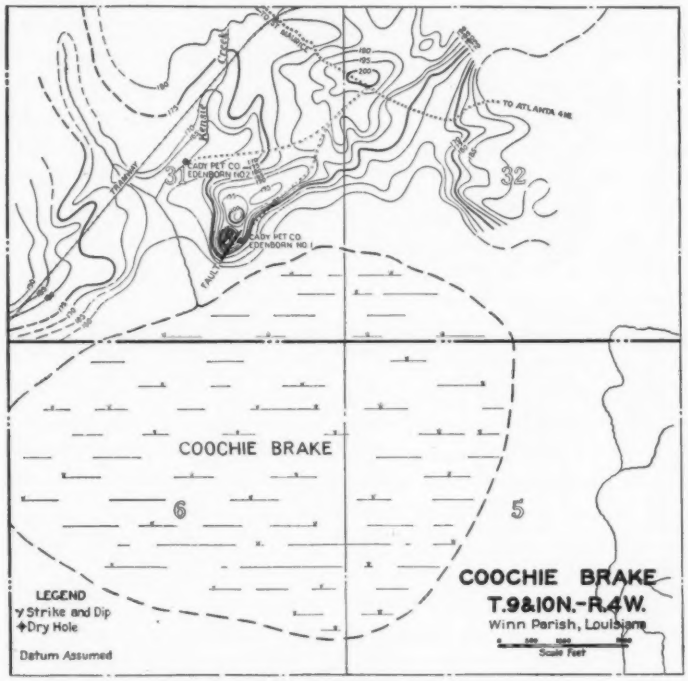


FIG. 25.—Topographic map of Coochie Brake

The slopes of the hills are covered with fine sand, effectually concealing any bedding that may be present. The only outcrop of importance in this locality is the ridge-forming limestone in the SE. $\frac{1}{4}$ of Sec. 31, T. 10 N., R. 4 W. The general features of this outcrop and its topographic expressions are shown in Figure 25. It is a massive calcareous sandstone containing many nodules of pyrite. Small fragments of lignite and some fossil leaves are found

in these beds, which, except for the greater amount of pyrite, are almost identical with those exposed at Drake's and Price's salt domes. The beds strike northeast, and although no distinct bedding planes are present, the inclination is definitely to the northwest.

UNDERGROUND GEOLOGY

The two wells drilled by the Cady Petroleum Company in Sec. 31, T. 10 N., R. 4 W., have furnished some information relative to the underground geology. However, these wells are located well down the flank of the uplift and did not reach the Cretaceous. Edenborn No. 1 well was junked at a depth of 1,912 feet, probably in the lower Wilcox, which, on the outcrop in Sabine Parish, would correspond to the Nanafalia beds. Edenborn No. 2 well, located 1,100 feet northwest of Edenborn No. 1, was abandoned at a depth of 3,100 feet, probably in the base of the Wilcox formation or in the upper part of the Midway formation. Chester A. Baird, geologist for the Cady Petroleum Company, supervised the drilling of these wells. According to Mr. Baird, Edenborn No. 1, located at the base of the limestone escarpment, found the top of the calcareous sandstone at a depth of 121 feet below the top of the escarpment, indicating a fault of approximately the same displacement. The same calcareous sandstone bed was found in Edenborn No. 2, located 1,100 feet northwest of Edenborn No. 1, 481 feet below the top of the escarpment, indicating a dip to the northwest of more than 20 degrees.

STRUCTURE

The 20-degree northwest dip on the north flank of Coochie Brake dome is even more impressive when it is considered that this dome is on the steeply southward-dipping Angelina-Caldwell flexure. Presumably the older Tertiary and Cretaceous rocks approach, or reach, the surface between the brake and the limestone outcrop. The center of the uplift, or that part of the dome underlain by the salt core, lies somewhere within the low marshy area known as Coochie Brake.

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The more important publications relative to the salt domes and the stratigraphy of this region are here given in chronological order:

1850. C. G. Farshey, "Louisiana: Geology and Hydrography (Abstract of Lecture)," *DeBow's Review*, Vol. 8, 1850. Notable mainly for containing the following statement concerning the north Louisiana salt springs: "A saline bed seems to underlie the Tertiary beds generally."

1867. J. B. Robertson, "Memorial and Explorations of the Honorable J. B. Robertson in Relation to Agriculture, Mineral, and Manufacturing Resources of the State, with a Report of the Joint Committee," *Doc. Second Session, Second Legislature, Louisiana, Report No. 23*, 1867; also separate, New Orleans, 1867, 30 pages. This report contains the first mention of the Cretaceous in Louisiana. The writer records that at King's salt works there are 200 feet of fossiliferous Cretaceous limestone.

1869. E. W. Hilgard, "Summary Result of a Late Reconnaissance of Louisiana," *American Journal of Science*, 2d Ser., Vol. 47 (1869), pp. 78–88. Hilgard established the presence of the Cretaceous by fossils found at King's salt works. From the relative geographical position of the different outcrops around the salines he concluded that there was in Louisiana a Cretaceous backbone, or ridge, extending in a general northwest-southeast line. He believed that at the beginning of the Tertiary this axis of elevation was marked by a number of islands in the Tertiary sea, and that they were finally covered with deposits of the younger formations.

1870–72. F. V. Hopkins, *First, Second*, and *Third Annual Report, Geol. Survey of Louisiana* (New Orleans, 1870, 1871, and 1872). In these reports the author reviews the geology of the state and includes the first geological map of Louisiana. He also refers to the vertebrate fossil remains found on several of the north Louisiana salines.

1873. E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana* (New Orleans, 1873). This report contains a more detailed description of the salines than is contained in the earlier publication of the same title.

1892. Otto Lerch, "A Preliminary Report upon the Hills of Louisiana North of the Vicksburg, Shreveport & Pacific Railroad, *Bull. Louisiana State Exp. Station, Geol. and Agr.*, Part I, 1892. Lerch added to the proof of the Cretaceous age of certain outcrops at Rayburn's saline by finding *Exogyra costata*. He held that about the close of Cretaceous time extraordinary disturbances took place which resulted in the formation of limestone peaks and mountain chains of considerable extent. One of these lines of disturbances was along the supposed Cretaceous backbone of Louisiana, and the various outcrops represent the partially buried peaks of this chain. He thought that the saline deposits were laid down in early Tertiary time, rather than in late Cretaceous time, as Hilgard had supposed.

1893. Otto Lerch, "A Preliminary Report upon the Hills of Louisiana South of the Vicksburg, Shreveport & Pacific Railroad," *Bull. Louisiana State Exp. Sta., Geol. and Agr.*, Part II, 1893. Describes Drake's saline and gives a list of all known or supposed Cretaceous outcrops.

1895–96. T. Wayland Vaughan, "The Stratigraphy of Northwestern Louisiana," *American Journal of Geology*, Vol. 15 (1895), pp. 205–29.

———, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142*, 1896. Vaughan concluded that no folding or faulting was represented in the north Louisiana Cretaceous outcrops; that they were butte-like masses, formed by erosion in the land interval which separated the deposits of the Cretaceous and Eocene, and has since been covered by the younger deposits.

1899. G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report for 1899*, Part V, 1900. This publication contains a wealth of information and the most complete description of the geology of Louisiana heretofore published. These writers were first to recognize the quaquaversal structure associated with the Cretaceous outcrops. They further pointed out that the folding occurred, in part at least, since the deposition of the Claiborne.

1902. G. D. Harris and A. C. Veatch, "A Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Part VI, 1902. This report is divided into several special papers. The Tertiary geology of the Mississippi embayment is described by Harris. The salines of north Louisiana are described in great detail by Veatch, who gathered a mass of historical data concerning the salt production. He reviews the evidence in support of the quaquaversal structure of the domes, and gives an ideal section of Drake's salt dome. He suggests that at the beginning of the Eocene they were either islands in the Tertiary sea or were so slightly submerged that the veneer of deposits they received was readily eroded in the following period; also, that the movement began in Cretaceous time and continued intermittently to the present time.

1906. A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, 1906. This paper contains an excellent summary of the geology of southern Arkansas and northern Louisiana. It reviews the geologic history of the salt domes as stated in the earlier publication. Veatch also suggests a volcanic origin of the domes.

1907. G. D. Harris, "Notes an the Geology of the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 5, 1907. Contains a detailed discussion of Winnfield Quarry, Cedar Creek, and Coochie Brake salt domes. An ideal section of Cedar Creek dome is given.

———, "Rock Salt," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 7, 1907. This comprehensive paper contains a brief résumé of all of the salt domes described in the earlier papers. The theories concerning the origin of the domes are reviewed and discussed.

1910. G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 429*, 1910. Contains a résumé of salt-dome data and a discussion of the occurrence of oil and gas.

THE ORIGIN OF THE FAULTS IN CREEK AND OSAGE COUNTIES, OKLAHOMA

LYNDON L. FOLEY
Wrightsman Petroleum Company, Tulsa, Oklahoma

ABSTRACT

The westward thrust of the Ozark uplift was opposed by the granite ridge of Kansas, causing rotational stresses in the formations lying between them. These rotational stresses caused shearing in directions approximately N. 25° E. and N. 65° W., and also tensional stresses in a northeast and southwest direction and compression in a northwest and southeast direction, as shown in the experiments of Mead. The conclusions are as follows: (1) The belts of short, *en échelon*, parallel faults were caused by horizontal movement along shear lines striking about N. 25° E. (2) The noses striking in a northwest direction were caused by shearing stresses along lines about N. 65° W., together with compression forces acting in a northwest-southeast direction. (3) The folds striking in a northeast-southwest direction were caused by compression forces described above. (4) These phenomena are the result of rotational stresses between the Ozark uplift and the granite ridge of Kansas.

In Creek and Osage counties, northeastern Oklahoma, there are long, narrow belts of short, parallel, *en échelon* normal faults which were studied and described by Fath.[1] These lines of faults extend southward into Okfuskee and Seminole counties, and one such line of faulting has been mapped in Payne and Lincoln counties (Fig. 1). Most of the individual faults trend about N. 20–40 W. and the lines of faulting trend north to N. 25 E., or at an angle of about 45 degrees with the trend of the faults. The fault planes dip either to the northeast or to the southwest, usually at an angle of about 45 degrees. Mr. Frank Greene, of Tulsa, states that he has found that about 80 per cent of the faults show a downthrow on the southwest side. The faults are of minor magnitude, both in vertical displacement and areal extent, the greatest stratigraphic throw observed in the Bristow quadrangle being 130 feet, and the greatest length, about $3\frac{1}{2}$ miles.

As the faults are of the normal type, the forces which caused them were probably tensional in nature, and operated in a direction normal to the strike of the faults, or about N. 45–70 E. The faulted

[1] A. E. Fath, "The Origin of the Faults, Anticlines, and Buried Granite Ridge of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128-C*, 1920.

SKETCH MAP SHOWING THE DISTRIBUTION OF EN ÉCHELON FAULTS AND THEIR RELATION TO THE OZARK-ARBUCKLE UPLIFT AND THE BURIED GRANITE RIDGE OF KANSAS.

—FAULTS ● GRANITE WELLS

FIG. 1

rocks at the surface are of Pennsylvanian age and are underlain by earlier Paleozoic rocks and the pre-Cambrian rocks of the basement complex.

In his discussion of the origin of these faults, Fath suggests that they were produced by horizontal movement along lines of weakness in the hard rocks of the underlying basement complex. He also suggests that vertical displacement along these lines of weakness would be even more common than horizontal movement, and that many of the folds are due to such vertical movement. He further notes the parallelism of the lines of faulting with the granite ridge of Kansas, and a tendency of many of the folds to alignment in the same direction, and suggests that all these features may have a common origin.

The dominating structural feature of the area under discussion is the Ozark uplift. This uplift caused a westward thrust which tilted the overlying Paleozoic beds to the westward, giving them an average dip of about 40 feet to the mile. This westward dip of the faulted formations continues southward into Hughes and Pontotoc counties, almost to the Arbuckle Mountains, so it is probable that the Ozark and Ouachita uplifts acted as a unit in tilting these beds. The buried granite ridge extends from Pawnee County, Nebraska, to Sumner County, Kansas, and projects upward through the Mississippian into the Pennsylvanian beds. The beds overlying the granite ridge are arched into a series of folds, and Fath[1] states that folding over the granite ridge continued into the Permian period. Many geologists consider these folds to be due to compacting and slumping, rather than to compressional folding. In either case, whether uplift along the line of the granite ridge caused an eastward thrust or whether the ridge merely acted as a passive buttress, it would resist the westward thrust of the Ozarks, which took place in post-Pennsylvanian time, and tilted the Pennsylvanian beds. These forces are represented on the map (Fig. 1) by the arrows *A* and *B*, and it will be seen that they are opposed in such a manner as to cause stresses of a rotational nature in the rocks lying between them.

[1] A. E. Fath, "Geology of the Eldorado Oil and Gas Field," *Geol. Survey of Kansas*, Bull. 7, 1921.

The action of rotational stresses as worked out by Leith[1] is illustrated by Fig. 2. In this sketch it will be seen that rotational stresses, such as those indicated by the arrows, would cause the

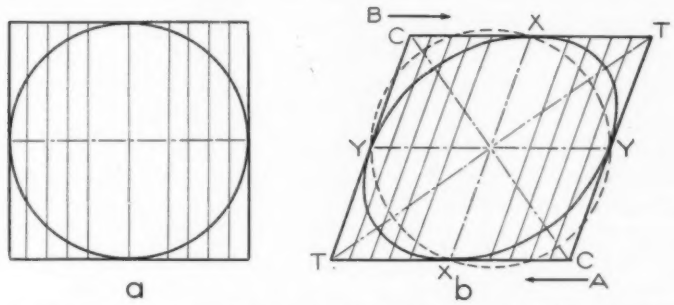

FIG. 2.—Sketch illustrating screen model used by Leith to show effect of rotational stresses. (*a*) Model before deformation. (*b*) Model after deformation. *XX* and *YY* are lines of distortion or lines of maximum shear. *TT* is axis of elongation or tension, and *CC* is axis of shortening or compression.

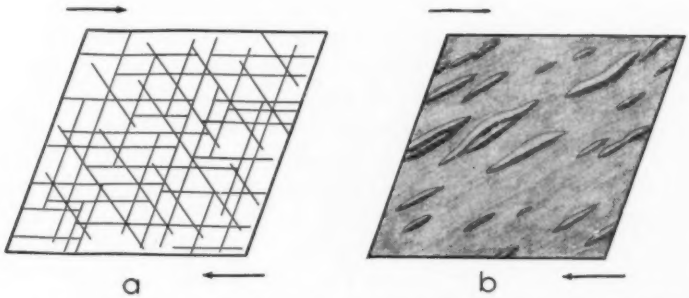

FIG. 3.—Sketches showing the results obtained by Mead in (*a*) fractures developed in brittle wax under rotational stresses; (*b*) folds developed in plastic wax under rotational stresses.

square to assume the shape of a parallelogram, while the circle becomes an ellipse. The model has been shortened or subjected to compression along the line *CC*, and lengthened or subjected to tension along the line *TT*. There is no change of dimensions along

[1] C. K. Leith, *Structural Geology* (revised ed., 1923), p. 26.

lines *XX* and *YY*, which are called the lines of no distortion, or lines of maximum shear.

The action of these forces is well illustrated by the experiments of Mead,[1] who used heavy sheets of rubber which he coated with paraffin wax and subjected to various types of deformation. Under rotational stresses the wax first developed tension cracks normal to the axis of elongation. These were followed immediately by two sets of vertical fractures with horizontal displacement, one set striking parallel to the direction of the forces, and the other nearly normal to them. The angle between the shear lines depends on the degree of the deformation. In the northern part of the Mid-Continent field the degree of deformation is slight, and it may be anticipated that the shear lines will be nearly normal to each other. Occasionally thrust faults developed normal to the axis of compression. These results are illustrated by Figure 3*a*. In Figure 3*b* is shown the type of folds developed by coating the rubber sheet with plastic wax and subjecting it to rotational stresses.

At the suggestion of Mr. K. C. Heald, the writer undertook laboratory experiments to test Fath's hypothesis regarding the origin of these faults. The experiments were performed in the laboratory of the University of Minnesota, using the type of compression machine developed by Bailey Willis.[2] In these experiments blocks of wood were used to represent the strong rocks of the basement complex. These were notched to prevent the overlying layers of wax from slipping over them, and were placed in the machine in such a position that compression of the model would cause horizontal movement between them. The less competent overlying beds were represented by layers of paraffin wax, some of which were softened by the addition of a few drops of crude oil. Diagonally opposite corners of the wax model were beveled, in order that the pressure might be applied at diagonally opposite corners. The model used is illustrated by Figure 4.

The model was placed in the machine and loaded with shot, as

[1] W. J. Mead, "Notes on the Mechanics of Geologic Structure," *Journal of Geology*, Vol. 28 (1920), p. 505.

[2] Bailey Willis, "Mechanics of Appalachian Structure," *U. S. Geol. Survey, Thirteenth Annual Report*, Part 2 (1893), Plate 66, opposite p. 258.

the wax tends to fracture, rather than fold, unless placed under some load. About 300 pounds of shot were used, giving a pressure of approximately 3 pounds per square inch. The compression was carried on very slowly, the screw being moved about 2 inches in eighteen hours.

The results of this experiment are illustrated in Figure 5. The plunger of the machine acted on the model at the point *A*, and the resistance of the end of the machine, at *B*. In the lowest wax layer a series of open tension fractures was developed, as shown in Figure

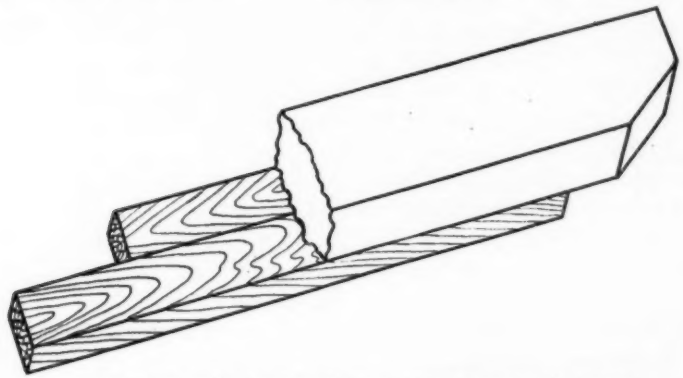

FIG. 4.—Sketch of model showing relative positions of wooden blocks before compression and beveling of wax layers at diagonally opposite corners of the model.

5*b*. The horizontal movement between the wooden blocks set up rotational stresses in the wax layer, and these tension fractures are normal to the axis of elongation. The fractures in the model are very similar to the fault lines in Creek and Osage counties, Oklahoma, and the experiment indicates that these faults were probably formed by horizontal movement along lines of weakness in the lower rocks, as suggested by Fath.

The fold which was developed in the wax layers is shown in Figure 5*a*. This fold is very similar to folds in the Mid-Continent field. It is interesting to note that the fold is steeper and more complex in the lower beds, and also that it is much narrower in the lower beds. The fold is steepest on the side opposite the moving plunger.

Applying these principles to the northern Mid-Continent area under discussion, the arrows *A* and *B* on the map (Fig. 1) represent the forces acting on the rocks of this region; the lines *XX* and *YY* represent the resulting lines of shear; the line *CC*, the axis of compression; and *TT*, the axis of elongation. The shear line *YY* is approximately parallel to the acting forces, and *XX* is nearly normal to them. Compressive forces would act parallel to the line *CC*, and

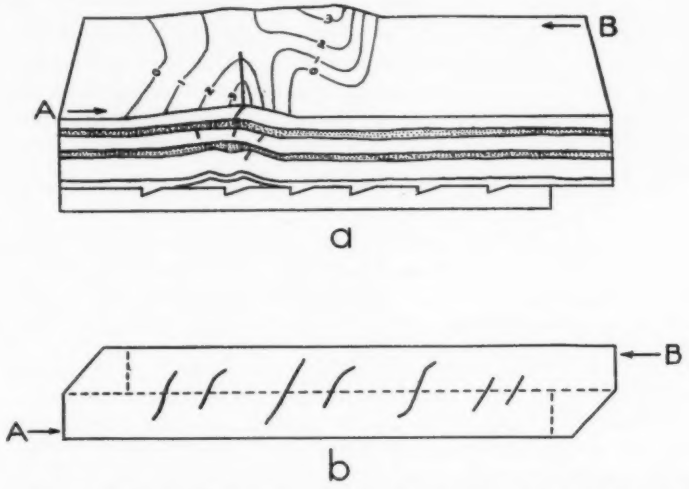

FIG. 5.—Sketch showing structure developed in wax model. (*A*) Point of application of pressure. (*B*) Point of resistance of end of machine. Stippled layers are softened wax. (*a*) Folds developed in wax layers. (*b*) Fractures developed in lowest wax bed.

tensional forces parallel to *TT*. According to the experiments of Mead, we would expect horizontal movement along these lines of shear. This shearing movement in the deep-lying competent rocks, together with the tensional stresses *TT*, would cause tension fractures striking about N. 40 W., and localized along the shear lines. The folds which are elongated in a northeast-southwest direction are approximately parallel to the shear line *XX*, and normal to the compression axis *CC*. The noses which strike in a north of west direction are parallel to the shear line *YY*.

The objection has been offered that across the state line in Kan-

sas, where good limestone outcrops occur, these faults have not been found, and that it seems strange they should disappear in a region of better outcrops. While I have not noted any actual faults, I have observed, in Cowley and Chautauqua counties, Kansas, fractures striking about N. 40 W., and dipping 45 degrees southwest. These fractures are parallel in strike and dip to the faults under discussion, and therefore probably belong to the same fracture system.

It is stated by many geologists of considerable experience that these faults do not persist in depth. Subsurface mapping shows faults in the Mississippian limestone which are parallel to the surface faults under discussion and probably belong to the same system. It seems quite natural that the faults in the relatively competent, limy, Upper Pennsylvanian should disappear downward, and those of the Mississippi lime disappear upward, into the thick, incompetent, Cherokee shale series.

It appears, therefore, that the lines of *en échelon* faults are due to shearing stresses incidental to rotational deformation between the Ozark-Ouachita uplift and the buried granite-ridge of Kansas. The principles of rotational deformation appear to account for all of the structural features in the area between the uplift and the granite ridge.

The parallelism of the lines of faulting and the granite ridge, which was noted by Fath, may indicate that the granite ridge itself is caused by uplift along a shear line, and that this whole system of shear lines must be referred to forces acting farther west, possibly to the Rocky Mountain uplift.

DISCUSSION

F. H. LAHEE: Mr. Foley, in this paper, has undertaken an explanation of a very interesting, but very difficult, problem. Lacking intimate acquaintance with the details of structural conditions in Oklahoma and Kansas, I do not feel able to discuss the subject as I should like to do. On one point in particular I cannot satisfy myself. I cannot conceive of a stratigraphic prism, like that which lies between the buried granite-ridge of Kansas and the Ozark Mountains, as a competent structure. I doubt whether a thrust applied by or at the Ozark mass could be transmitted, essentially in a horizontal direction, through this stratigraphic prism to and against the granite ridge, this ridge serving as a buttress. The distance between the granite ridge and the Ozarks is over 100

miles. I do not believe that the sediments, in themselves, are sufficiently competent to carry such a thrust so far.

If this is the case, we must assume that any thrust such as Mr. Foley postulates would be transmitted, probably in large degree, by the underlying basement complex, and that the sedimentary prism would be largely supported by the basement complex. On this assumption, are we not brought back to the interpretation of Fath, that the structures in the sediments are secondary effects of forces acting in the basement? Can Leith's strain-ellipse diagram be applied to the actual conditions in the simple manner suggested by Mr. Foley?

If we look into the matter a little more closely, we find that, in postulating a *rotational* stress, Mr. Foley indicates, not a direct thrust from the Ozarks to the granite ridge, but an indirect thrust from the Ozarks westward and to the south of the granite ridge, and from the granite ridge eastward toward a point north of the main mass of the Ozarks. The thrust represented between the Ozarks and the granite ridge is merely a component of a shear due to this rotational stress, provided Mr. Foley is right. Does not this hypothesis of indirect compression imply an even greater competency in the sediments than a direct thrust?

MR. FOLEY: Fath stated that the sedimentary rocks of this region, particularly the Pennsylvanian sediments, would be incompetent to transmit the stresses which deformed them and that the stresses were probably transmitted through the hard rocks of the basement complex. This point should have been given greater emphasis in my paper. In the paragraph beginning "Applying these principles to the northern Mid-Continent area," I said "This shearing movement *in the deep-lying competent rocks* together with the tensional stresses *TT*, would cause tension fractures, striking about N. 40 W., and localized along the shear lines." Although the structures in the sediments are the result of forces transmitted through the basement rocks, I believe that the principles of the strain ellipsoid can be applied.

W. TAYLOR THOM, JR.: Mr. Foley has presented a very interesting confirmation of the theory that the belts of *en échelon* faults, so conspicuously shown by the Oklahoma areal map, are due to rotational stresses set up in the surface strata by horizontal movements on shear planes in the basement rocks. I do not, however, agree that the Ozark region played a very active rôle as an agent responsible for the production of the fault belts and associated features, believing that the Choctaw and associated thrust faults of the Ouachita Mountains show that this mountain mass was crowded northwestward into the gap between the Ozarks and Arbuckles. This crowding was accompanied by northwestward and northward thrust in the granitic basement rocks, which was largely relieved by horizontal movements on northeastward-trending pre-Cambrian shear planes in the basement complex.

MR. FOLEY: It was suggested in my paper that the Ouachita uplift had probably influenced the deformation of this region. It may have been the

dominating feature as Dr. Thom suggests, although Fath refers to the Ozark uplift as "the dominating structural feature in the northern part of the Mid-Continent field."

W. A. J. M. VAN DER GRACHT: I compliment Mr. Foley on his excellent analysis of the details of the deformation of the blanket over the deeper basement in Oklahoma. This deformation is the reflection of drift or flowage in the deeper basement. It affected two blankets: first, a less complete blanket, containing only beds up to the Mississippian, inclusive; second, a more complete blanket, including Pennsylvanian and Permian. This first deformation is evidently Hercynian; we cannot time the second phase for lack of younger beds than the Permians; probably it is Laramide, or it may be, still younger.

If a continent is deformed, the stresses are most strongly expressed along its more yielding borders, but nothing being absolutely rigid, these stresses act everywhere. The relatively more rigid continent also is not at all homogeneous: there are more rigid and more compact areas in the continental shell, as these influence the details of deformation and may very well set up rotary movements. The original basal "grain" always plays a great part, and this also was apparently north-south in this part of the North American continent. That this is parallel with the Pacific front is only a natural consequence. There is no disagreement whatever here between Dr. Thom and myself.

Such detailed work as Thom and Foley did will work out the general principles, which I described this morning, into features of the highest practical interest for exploration.

W. W. RUBEY: Mr. Foley has mentioned that no lines of *en échelon* faults comparable with those in Oklahoma are known west of the granite ridge in Kansas, but it is worth noting that most of the prominent structural features between the granite ridge and the Rocky Mountain front show an orientation similar to that of the Oklahoma fault belts.

The rather steep-sided and straight Fairport-Natoma anticline in Russell County, Kansas, trends slightly east of north. A prominent anticline extends north through western Kansas, but may possibly turn northwestward under the Tertiary cover in western Nebraska (*U. S. Geol. Survey Bull. 691*, Plate 1). The narrow, straight, and very steeply dipping Stockade Beaver monocline in the Black Hills in northeastern Wyoming trends north-northeast, and seems to be connected with the Old Woman anticline and the Hartville uplift in eastern Wyoming (*U. S. Geol. Survey Bull. 691*, Plate I, and Newcastle Folio, Fig. 3). The steeply dipping eastern margin of the Laramie Mountains in southeastern Wyoming and the Front Range in Colorado has the same orientation. A buried mountain-ridge overlain by an anticline in the surface rocks probably extends northeast through eastern New Mexico into Colorado (this *Bulletin*, Vol. 5, pp. 605–8; *U. S. Geol. Survey Bull. 726*, Fig. 16; *U. S. Geol. Survey Bull.* Plate 1).

In the Black Hills, the Stockade Beaver monocline has the same orientation

as that reported for the unmodified cleavage of the pre-Cambrian rocks there (*Bull. Geological Society of America*, Vol. 1, pp. 209, 231–33, 241), and a parallelism between the Colorado Front Range and the trend of its pre-Cambrian structure is reported (*Bull. Geological Society of America*, Vol. 34, pp. 700–701). Although these structural features are distributed over a very large area, their essentially parallel orientation suggests a possible relationship that should be considered in any discussion of the origin of the Oklahoma fault belts and the granite ridge of Kansas.

VIRGIL O. WOOD: I should like to ask Mr. Foley, whether his experiments were carried to the point where suggestions were evidenced as to which side of the fractures or faults might be predominantly downthrown? It has been my experience in working among and with faults of this region that the majority are downthrown to the east, rather than to the west.

MR. FOLEY: The experiments were not carried to such a point that these determinations might be made.

L. G. WELSH: Mr. Foley has quoted Frank C. Greene as stating that in 80 per cent of the faults in Osage, Creek, and Okmulgee counties, Oklahoma, the downthrow side is on the southwest side of the fault. I do not agree with this, and want to know if the data collected by Mr. Foley on the faults he has plotted bear out Mr. Green's statement. From my experience in this same area I would say that just the opposite is true, namely, that the downthrow is on the northeast side, in a ratio of almost two to one.

MR. FOLEY: Mr. Greene made this statement as an off-hand answer to a question asked of him during an informal discussion at a meeting of the Tulsa Geological Society but he did not intend it to apply to Okmulgee County. In some areas, the downthrow is predominantly to the southwest while in others it is predominantly to the northeast. I do not know that anyone has counted the known faults to make a quantitative determination. It appears that the opinions of various geologists as to the relative predominance of the two directions of downthrow are due to their own particular experiences.

SOME FEATURES OF REDBED BLEACHING[1]

GAIL F. MOULTON
Illinois Geological Survey[2]

ABSTRACT

Field work in southern Montana has led to the discovery that in certain folds on the flanks of the Bighorn Mountains, the Chugwater redbeds exposed along the crests of minor anticlines are bleached to a clean white color. Oil seeps were noted in the Chugwater sandstone at the south end of one of these anticlines along the Little Bighorn River. Later a much larger mass of oil-saturated rocks was found in the Chugwater formation on the Black dome, southeast of Bridger. These occurrences suggest that oil migrating through the sands causes a reduction of the ferric oxide pigment to a soluble ferrous form in which solution and removal take place. Laboratory experiments showed that no appreciable reduction took place unless the temperature was raised enough to cause cracking of the oil. At such temperatures the reaction was rapid. Further investigation resulted in the discovery that hydrogen sulphide reduces ferric oxide in the cold. This fact has long been made use of by gas chemists in purifying coal gas. In the case of the bleaching near Bridger, it is clear that hydrogen sulphide is a possible agent, for in that locality a spring of water containing a large quantity of that gas was noted. Hydrogen sulphide has been shown to be a common constituent of waters associated with oil. Such waters would probably follow or accompany oil escaping through fissures in an anticline. Therefore, although the bleaching is probably not due to the action of the oil itself on the ferric oxide, it may be considered as a phenomenon associated with the movement of oil through the rocks. Consequently any anticlines whose crests are marked by bleached redbeds should be regarded with suspicion unless possibilities of production exist at a considerable depth.

INTRODUCTION

The Chugwater formation of Wyoming and southern Montana is a distinct series composed of brilliant red sandstone, sandy shale, and shale. The red color is a characteristic feature over a large area extending from the Black Hills around the Bighorn Mountains and into southern Wyoming at least as far as the Rawlins Hills. The color has been useful in stratigraphic correlations because of its uniformity.

During the course of field work for the United States Geological Survey in southern Montana, several localities were found at which the Chugwater redbeds had been bleached so that they are untinted white. These localities are indicated on the generalized map of the

[1] With permission of the director, United States Geological Survey.

[2] By courtesy of the Chief, Illinois State Geological Survey.

region of work (Fig. 1). The Sport Creek, Willow Creek, and Reed domes have been described.[1] The Black dome southeast of Bridger is well known and has been tested for oil.

FIELD CONDITIONS

Observations in the field show that the general relations of bleaching to structural features are identical for all of the localities found; namely, that the bleaching occurs along the crests of minor

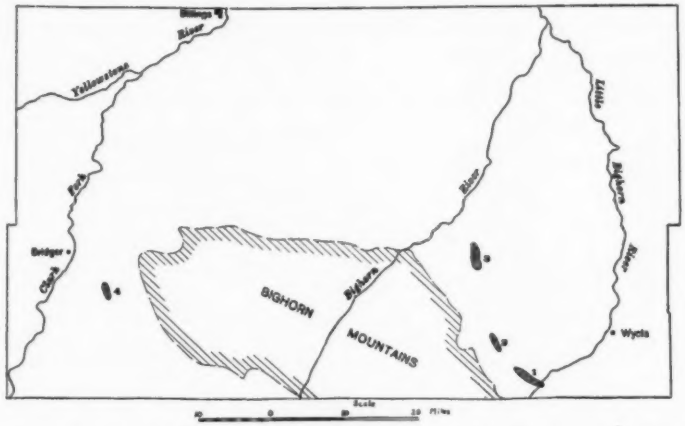

FIG. 1.—Sketch map of region near Billings, Montana. (1) Sport Creek Anticline. (2) Willow Creek—Reed dome. (3) Soap Creek dome. (4) Black Gulch dome.

folds on the flanks of the main mountain uplift. Due to variations in local conditions, some of the detailed features of the bleaching are best shown in one locality, and others in another. Accordingly, the critical features found in each locality will be described briefly.

The Sport Creek dome is a sharp fold on the eastern flank of the Bighorn Mountains. The area of bleached redbeds exposed here is large, and extends for more than a mile along the axis of folding. In this locality the relations of structure to bleaching are well shown. Figure 2 is a cross-section of the Sport Creek dome. Fractures caused by strains during folding are prominently developed here and

[1] W. T. Thom, Jr., "Oil and Gas Prospects in and near the Crow Indian Reservation, Montana," *Bull. 736-B, U. S. Geol. Survey* (1922), p. 50.

probably played an important rôle in the bleaching process. Oil-saturated sandstones are found on the south end of the Sport Creek dome where it is crossed by Little Bighorn River. These beds have been described as Tensleep,[1] but may be Chugwater.

The conditions in the Willow Creek and Reed dome localities are very similar except that no considerable masses of oil-saturated rock are found. Tests on some of the bleached rock,[2] however, show that minute brown spots in it were composed of a tarry residue.

The Black dome occurrence near Bridger on the west side of the Bighorn Mountains is somewhat similar to the others. Here a larger

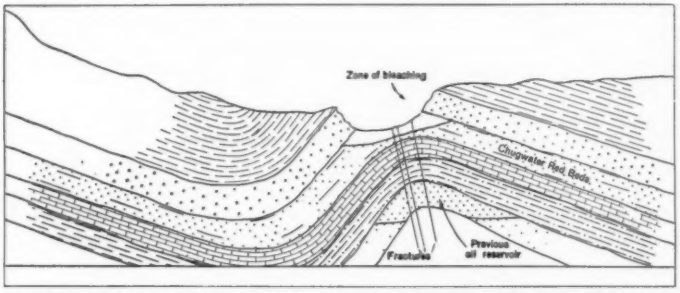

FIG. 2—Typical relations of structure and bleaching as shown at Sport Creek

bleached area is found associated with great masses of oil-saturated sandstone.[3] In all places observed, there is a thickness of ten feet or more of bleached beds between the oil saturated rock and the beds with the original red color.

Black dome is of interest because of the detailed relations between fracturing and bleaching which are shown there. Figure 3 represents the results of observations on the south side of the dome. The lower sandstones are completely bleached, but those above are bleached to a lesser extent, reaching a limit at which bleaching is restricted to the borders of the joint planes themselves. The bleaching took place most readily along the joints, and at greater distances from the joints in the more open porous layers of the redbeds than in the finer more compact layers. This relation of the oil saturation, bleaching, and joints indicates that the bleach-

[1] W. T. Thom, Jr., *loc. cit.* [2] W. T. Thom, Jr., Personal communication

[3] Called to the attention of the writer by R. S. Knappen.

ing agent moved up from depth through the fissures, and that either the oil, or associated substances, or both caused the bleaching action.

On the north side of the Black dome there is a spring of water

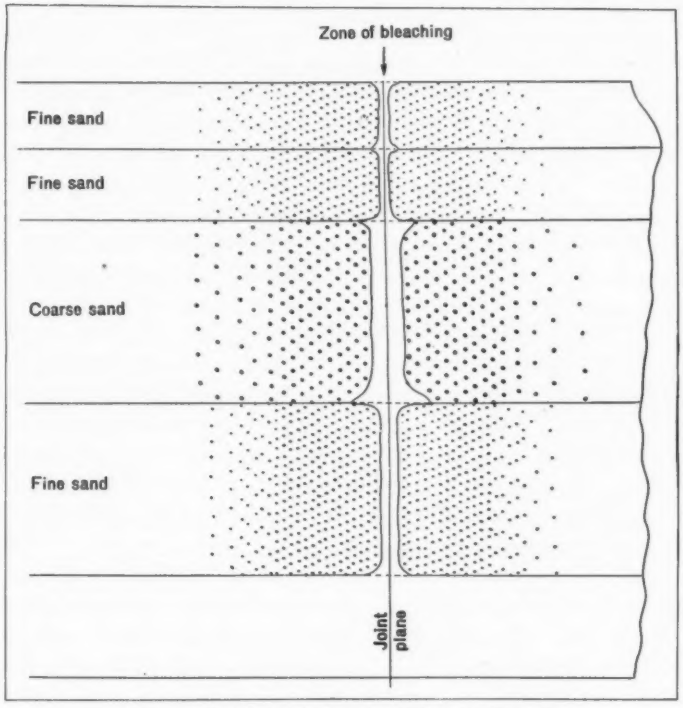

FIG. 3.—Sketch of relations of bleaching to jointing

containing a large amount of hydrogen sulphide. Water of this kind appears to be rather common in the porous Tensleep and Amsden beds on local anticlines and associated with the heavy black oil of the region. It has been reported from some of the wells on the Soap Creek dome.[1] The presence of this type of water has been found to have an important bearing on the problem of redbed bleaching.

[1] *U. S. Geol. Survey Press Notice 12798.* Recent drilling in the Soap Creek field, Crow Indian Reservation, Montana, May 3, 1922.

The chemical change involved in bleaching.—Analyses have been made which show that the red color of the Chugwater beds is due to the presence of an iron oxide coating on the grains.[1] In the samples investigated both ferrous and ferric oxide were present in the proportions of one part ferrous to two ferric. The oxides averaged 1.52 per cent of the rock as ferric oxide. Since ferric oxide has a brilliant color, the loss of color is evidently due to a loss of ferric oxide either by chemical change, removal, or both. It is evident that reduction of the derric oxide to the duller more soluble ferrous form would promote bleaching, both by destroying the color of the pigment of the rock and by making easy solution of the altered material possible, so that later oxidation would not restore the red color. Accordingly, experiments were made on ferric oxide reduction in order to determine the conditions of reduction and the significance of the bleaching.

EXPERIMENTAL WORK

Experiments with crude oil.—Crude petroleum seemed to be the obvious reducing agent available for the bleaching of the redbeds. Therefore, experiments were undertaken to test the idea that crude oil would reduce ferric oxide at moderate temperatures. Simultaneously, a search was made through "Chemical Abstracts" for results of similar work. No paper was found which appeared to have any direct bearing on the problem.

Like other attempts to duplicate geologic conditions, the experiments on ferric oxide reduction were handicapped by a lack of time and pressure. The original plan, therefore, was that the experiment should be carried out, first at temperatures at which the reduction would be relatively rapid, then at successively lower temperatures until either the rate of reduction could not be measured, or until ordinary temperatures were reached. Measurements of the various rates of reduction would then be available for drawing a curve to show the rate of reduction as a function of the temperature. This curve projected to temperatures which could reasonably be assumed to have existed would show the rate of reduction in the bleaching process.

In the first experiments, specimens of the Chugwater redbeds

[1] Analyses made in the chemical laboratory, University of South Dakota.

were ground to a flour and sieved through a 200-mesh screen. After thorough mixing, the finely pulverized rock was stored in a stoppered bottle. Samples were weighed out for experiment and analysis. The samples used in the experiments were placed in flasks with crude oil and heated on an electric hotplate. Temperatures as high as 275° C. were maintained for two weeks. Other sets of samples were treated at lower temperatures for similar periods of time. After heating, the samples were treated in a Soxhelt extractor to remove all traces of crude oil, and then analyzed for ferric and ferrous oxides.[1] No appreciable reduction could be determined from any of twenty analyses of samples treated under various conditions.

The following year a series of experiments was undertaken along different lines. Ferrous-free ferric oxide was used so that reduction could be determined by qualitative methods. Some of this oxide was pulverized and put in a hard glass tube heated by an electric coil. Vapors of crude oil from Soap Creek field were passed over it. No reduction could be detected unless the temperature reached the point necessary to cause cracking of the vapor. At these higher temperatures, however, the reduction was rapid and the cracking was indicated by the formation of a tarry residue in the tube.

As a result of these tests it was concluded that no marked reduction of ferric oxide is caused by the action of crude oil under atmospheric pressure unless the temperature is high enough to cause cracking.

Experiments with hydrogen sulphide.—Field observations suggested one other possible bleaching agent: hydrogen sulphide. Accordingly, experiments were undertaken to determine the effect of hydrogen sulphide solutions on ferric oxide.

Hydrogen sulphide gas was generated by the action of sulphuric acid on iron sulphide, passed through a wash bottle to remove any acid, and bubbled through a flask of distilled water containing some powdered ferrous-free ferric oxide. This action was allowed to proceed for several hours. Then the flask was heated until a test showed that the hydrogen sulphide had been removed, and the material was dissolved in hydrochloric acid. Tests showed an abundance of fer-

[1] For method see W. F. Hillebrand, "Analysis of Silicate and Carbonate Rocks," *U. S. Geological Survey Bull. 700* (1919), pp. 124–25, 196–206.

rous iron to be present. Since hydrogen sulphide was not present simultaneously with any other acid, it may be concluded that the reaction can take place under natural conditions, and at common surface temperatures and pressures.

NOTES ON THE ACTION OF HYDROGEN SULPHIDE ON FERRIC OXIDE

A subsequent investigation showed that the reaction between hydrogen sulphide and ferric oxide has been employed for some time as a means for removing hydrogen sulphide from artificial gas for city use. In a recent report[1] it was stated that a good iron oxide for gas purification under favorable conditions will remove all of the hydrogen sulphide from the gas passed through it until 80 per cent of the iron oxide has been reduced, much of it to a sulphide. This experimental result may be used as a measure of the speed and completeness of the reaction between iron oxide and hydrogen sulphide. During the experiments of the Bureau of Mines it was also found that the presence of water was effective in slowing the process.[2] A loss in the speed of reaction is not a serious matter in the present case, however, for the time available is very great. Consequently, it seems best to use the sulphide reaction as the basis for an explanation of the bleaching of the redbeds in the localities described.

THE BLEACHING PROCESS

It is believed that hydrogen sulphide was the reducing agent, because the experiments failed to show the possibility of reduction of ferric oxide at ordinary temperatures by oil, but demonstrate the possibility of reduction by hydrogen sulphide. It is well known that hydrogen sulphide is a common gas in waters associated with oil and such an association is reported from the Soap Creek field. A spring of this type of water was found in one of the bleached areas as well. Therefore, there can be little question that hydrogen sulphide was available.

The evidence collected indicates that the bending of the strata at the crests of the minor folds on the flanks of the Bighorn uplift was

[1] W. A. Dunkley, and R. D. Leitch, "Conditions Affecting the Activity of Iron Oxides in Removing Hydrogen Sulphide from City Gas," *U. S. Bur. of Mines, Tech. Paper 332* (1923), p. 4.

[2] *Op. cit.*, p. 10.

so sharp that fracturing and minor faulting were common in some of the more competent beds. Advancing erosion, long after the epoch of mountain folding, carried away the soft impervious shale covers of such folds and left the fractures as open avenues of escape for any fluids which might enter under pressure below. Oil accumulation had taken place in the Paleozoic rocks along some of these folds. This oil and the water with it were now able to escape through the fissures. During the escape, hydrogen sulphide, which was probably present both in the oil and the water, acted on the ferric oxide in the redbeds with which it came into contact. The reducing action resulted in the bleaching of the red color.

SIGNIFICANCE OF THE BLEACHING

The bleaching of redbeds in such circumstances has a significance to the oil geologist which should not be overlooked. The fact that bleaching has taken place indicates that an avenue for fluid escape has been established between beds at depth which might have contained oil or gas, and the bleached beds at the surface. Therefore, if oil has accumulated under the anticline along which bleaching is found, there has been an opportunity for its escape. Unless the structure is of such size that a large amount of oil should have been present, or unless a second oil-bearing horizon is expected at depth and separated from the first by soft shales, anticlines whose crests are marked by bleached redbeds should not be given favorable consideration as possible oil producers. This rule should have general application to other regions and to similarly uniform redbeds.

ACKNOWLEDGMENTS

Appreciation is here expressed of the co-operation of the Midwest Refining Company in supplying redbed core samples and crude oil from the Soap Creek field. Dr. A. H. Pardee, of the department of chemistry, University of South Dakota, made many valuable suggestions regarding the experiment. K. C. Heald also stimulated the work in many ways.

DISCUSSION

W. A. J. M. VAN DER GRACHT: Bleaching along faults is very common in Triassic redbeds of Western Europe, in regions where there cannot be question anywhere of hydrocarbons. Probably it is due to sulphur water or gases, as pyrites and other sulphides can often be observed on such faults.

GEOLOGICAL NOTES

THE WIGGLESTICK

A very surprising paper[1] has come to hand in which Johannes Walther asserts a strong belief in the ability of wigglestickmen to detect and map subsurface deposits of water, petroleum, salt, potash, coal, and minerals.

In the period between the end of the war and the writing of that paper, Walther apparently spent much time with wigglestickmen and in the observation of the behavior of wigglesticks in the hands, both of experienced wigglestickmen and of his students. He has come to the conclusion that many people have the ability, in varying degrees, to feel the presence of water, petroleum, salt, coal, potash, minerals, etc., somewhat similarly as many people are sensitive to musical sounds; that the presence of these substances stimulates in some way the nervous systems of such people, so that a certain feeling is caused in their tissues, or movements are set up in their muscles, either with or without the wigglestick; that after long practice, a wigglestickman can come to more or less certain conclusions in regard to the subsurface distribution of these substances; and that the wigglestick itself is merely a mechanical device for amplifying the muscular reactions. The first half of the paper is an elementary exposition of the occurrence of water in the earth's crust. The second half is devoted to a description and discussion of the wigglestick phenomena. Detailed data to support his startling conclusion that certain persons are able to "feel" as it were the presence of these substances are not given. He describes the muscular reactions which seem to underlie the behavior of the wigglestick. Only two actual experiments are described. He sent a number of experienced wigglestickmen and more than one hundred students with wigglesticks over the same course and observed that most of the reactions came within certain narrowly delimited spots; and later he sent those of his students who seemed to have the gift of wigglestick "sensitivity," one by one alone over a definite course and found a remarkable coincidence in the positions of the wigglestick reactions of the various students. Although he makes the statement that he knows of numerous cases in which wigglestickmen determined with great certainty

[1] *Das untererdische Wasser und die Wünschelrute*, ein Vortrag von Johannes Walther. Press of Emil Hampel, Weisswasser-O-L, undated, later than 1921. 32 pp.

the presence and exact depth of water, salt, coal, and ore, he gives no details regarding the conditions under which the wigglestickmen made their determinations, and fails to present evidence to connect the observed muscular and nerve reactions with the presence of water, salt, or any other substance below the surface.

From the paper the writer gains the impression that Walther was impressed with the sincerity of belief of most of the wigglestickmen, that he observed the actual fact of the wigglestick reactions, and on account of the coincidence in position of the reactions in the experiment mentioned above, was forced to seek some external cause, acting at certain spots to produce the reactions in the students, that he rather uncritically accepted the assertions of wigglestickmen in regard to the determinations that they had made in regard to subsurface deposits of water, salt, coal, metals, etc.; and that, without scientific or logical warrant, he accepted the wigglestickmen's explanation that it is some effect of the presence of these substances below the surface that sets the wigglestick reactions in motion.

The conclusions of Johannes Walther have been, and ordinarily must be, respected by scientists, but these conclusions state as facts things which seem to have such an extremely low order of probability as to be entirely improbable in the ordinary sense of the word. The German Geological Survey in 1920 carried out successfully a series of tests of the wigglestick under correct scientific control and under conditions in no way inimical to the wigglestick and got results entirely adverse to the ability of three experienced wigglestickmen to determine or map the presence of water, salt, potash, coal, ore, or faults.[1]

It will take some such series of field tests run under correct scientific control and resulting favorably to the wigglestick, to prove that wigglestickmen are not frauds, whether consciously or unconsciously so. If Walther's belief in the wigglestick reactions is based on such evidence, which will stand scientific criticism, it is unfortunate that he did not at least sketch an outline of it, and it is to be hoped that he will publish it to support conclusions which, to American scientists at least, seem so to transcend scientific probability.

DONALD C. BARTON

RYCADE OIL CORPORATION
HOUSTON, TEXAS

[1] *Preuss. Geol. Landesanstalt:* "Zur Wünschelrutenfrage Nr. 1," 1921, reviewed by D. C. Barton. "The Wigglestick," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 7, 1923, pp. 427–29.

REVIEWS AND NEW PUBLICATIONS

The Bureau of Economic Geology of the University of Texas has recently issued two reports: *Bull. 2509*, "Etched Potholes," by J. A. Udden, 9 pp., 2 figs., 6 pls.; and *Bull. 2539*, "The Lytton Springs Oil Field," by H. P. Bybee and R. T. Short, 71 pp., 3 figs., 9 pls., including description of the igneous rock by J. T. Lonsdale, T. L. Bailey, and Marcus A. Hanna. Publications announced for issuance in the near future are: *Bull. 2544*, "The Geology of Denton County," by W. M. Winton, and *Bull. 2607*, "The San Angelo Formation and The Geology of Foard County," by J. W. Beede and D. D. Christner.

Principles of Soil Mechanics. By DR. CHARLES TERZAGHI, Professor of Civil Engineering, American Roberts College, Constantinople, Turkey. *Engineering News-Record*, Vol. 95, No. 19, November 5, 1925. "Phenomena of Cohesion of Clay": Relation between load and moisture-content—Hydrostatic stress in clay—Shrinkage and negative hydrostatic pressure—Surface tension the cause of cohesion. Vol. 95, No. 20, November 12, 1925. "Compressive Strength of Clay": Modulus of elasticity determined from cube tests at different moisture contents shows constant ratio to capillary pressure—Poisson's ratio for clay—Analogies with metals—The Iowa experiments. Vol. 95, No. 21, November 19, 1925. "Determination of Permeability of Clay": Validity of Darcy's law—Slichter's formula and Hazen's observations—Permeability of sand—Experiments on clay—Darcy's law valid even for semi-solid state. Vol. 95, No. 22, November 26, 1925. "Settlement and Consolidation of Clay": Consolidation the result of decrease of moisture content under load—Change in hydrodynamic stress—Typical computations—Application to permeability determination. Vol. 95, No. 23, December 3, 1925. "Physical Differences Between Sand and Clay": Commonly noted differences in behavior—Grain size and a new uniformity diagram—Shape of grains and structure—How shrinkage, cohesion, plasticity, and settlement are affected. Vol. 95, No. 25, December 17, 1925. "Elastic Behavior of Sand and Clay": Testing sand for compressibility and elasticity—Expansion and resaturation—The ideal sand cube and the effect of lateral expansion—Comparison with solids. Vol. 95, No. 26, December 24, 1925. "Friction in Sand and in Clay": Complex nature of friction in granular masses as compared with solid friction—Measuring friction in sand and clay—Two kinds of frictional motion in sand—Hydrodynamic effect on clay friction. Vol. 95, No. 27, December 31, 1925. "Future Development and Problems": Origin and history of experimental

study of soils—Future objectives—A theory of models—Soil classification —The method of equivalents for engineering practice.

Doctor Terzaghi's articles on the "Principles of Soil Mechanics" contain many data of importance to petroleum geologists. The author has carried on an extensive experimental study of the physical behavior of sand and clay, the work being done at Roberts College, Constantinople. His investigations of physical properties of clays cover a field heretofore essentially unexplored and the paper gives comparative data on sands and clays showing wherein their physical properties are similar and wherein they differ. He discusses grain sizes and structure, for sand and clay, and gives a "new uniformity diagram." He also discusses the shape of sand and clay grains as well as demonstrating how shrinkage, cohesion, plasticity, and settlement are affected.

The discussion of the action of capillary pressures in clay-water mixes, in causing shrinkage, should be particularly informative to the research geologist. In fact, the subject of clay is covered in a thorough and convincing manner from permeability to the "Brownian movement" of its colloids.

The author concludes that throughout his studies he found no essential difference between sand and clays other than the difference in grain size and shapes. He shows, however, that these two differences are fully adequate to explain the more obvious distinguishing features of the two materials.

R. E. COLLOM

THE ASSOCIATION ROUND TABLE

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS MEMBERSHIP LIST

March 1, 1926

FULL MEMBERS

Abrahamson, Hjalmar, 518 U.S. Bank Bldg., Denver, Colo.
Absher, William F., Empire Gas & Fuel Co., Geol. Dept., Bartlesville, Okla.
Adams, George I., University of Alabama, Tuscaloosa, Ala.
Adams, H. H., 415 W. T. Waggoner Bldg., Fort Worth, Tex.
Adams, Noah C., Box 109, Tulsa, Okla.
Adams, William C., 729 Kennedy Bldg., Tulsa, Okla.
Adkins, W. S., American University Union, 173 Blvd., St. Germain, Paris, France
Adrian, Dr. H., Graffenriedstrasse 24a, Muri bei Bern, Switzerland
Aid, Harry, Box 248, Gulf Prod. Co., Amarillo, Tex.
Aid, Kenneth, Box 505, San Angelo, Tex.
Ainsworth, Wm. L., 301 N. Yale St., Wichita, Kan.
Albertson, Maurice M., Apartment 19, 6057 Waterman Ave., St. Louis, Mo.
Alden, John M., U.S. Geol. Survey, Box CC, Taft, Calif.
Allen, Bryant, Box 12, Laredo, Tex.
Allen, E. G., Roxana Petroleum Corp., Mayo Bldg., Tulsa, Okla.
Allen, Walter J., 705 Kennedy Building, Tulsa, Okla.
Ambrose, A. W., Empire Gas & Fuel Co., Bartlesville, Okla.
Ames, Edward W., Box 818, Cisco, Tex.
Ames, Elmer R., 2485 N. Gower St., Hollywood, Calif.
Anderson, Amil A., 304 Bitting Bldg., Wichita, Kan.
Anderson, Carl B., 804 Kennedy Bldg., Tulsa, Okla.
Anderson, Frank M., 58 Hillcrest Road, Berkeley, Calif.
Anderson, G. E., 411 East Keith, Norman, Okla.
Anderson, J. G., Jr., Box 412, Clarksville, Tenn.
Anderson, Robert V., Menlo Park, Calif.
Andresen, Lewis Paul, address unknown
Andrews, Sylvan H., Box 471, Okmulgee, Okla.
Applin, Esther E. (Mrs. Paul L.), 326 Southern Pacific Bldg., Houston, Tex.
Applin, Paul L., 320 Southern Pacific Bldg., Houston, Tex.
Armstrong, J. M., Prairie Oil & Gas Co., Eastland, Tex.
Arnold, Ralph, 639 S. Spring St., Los Angeles, Calif.
Artman, George W., 515 W. Cleveland, Ponca City, Okla.

Aronson, Sam M., 701 Magnolia Bldg., Dallas, Tex.
Ashley, George H., State Capitol, Harrisburg, Pa.
Athy, Lawrence F., 201 North 3d Street, Ponca City, Okla.
Augur, Irving V., 227 Story Bldg., Los Angeles, Calif.
Aurin, Fritz, Marland Refining Co., Ponca City, Okla.

Bailey, Thomas L., 1314 Poli St., Ventura, Calif.
Baird, Chester A., Apartado 234, Venezuelan Gulf Oil Co., Maracaibo, Venezuela, S.A.
Baker, Charles L., 1209 Shattuck St., Berkeley, Calif.
Baker, Raymond F., Drawer F, The Texas Co., Geol. Dept., Houston, Tex.
Baker, William A., Jr., Apartado 657, Tampico, Mexico
Baldwin, H. L., Fort Stockton, Pecos County, Tex.
Baldwin, Harry L., Jr., Box 1169, Denver, Colo.
Ball, Max W., 1104 First National Bank Bldg., Denver, Colo.
Ball, Sydney H., Room 1414, 42 Broadway, New York City
Barbour, Erwin H., University of Nebraska, Lincoln, Neb.
Barnes, Roy M., 2140 Rose St., Berkeley, Calif.
Barnett, Donald G., 811 Frost National Bank, San Antonio, Tex.
Barrett, William G., Box 31, Farmington, Mo.
Barrow, Leonidas T., 1118 W. French Place, San Antonio, Tex.
Bartlett, Fred W., Box 1162, Tulsa, Okla. (Mail returned)
Barton, Donald C., Box 1817, Rycade Corp., Houston, Tex.
Barton, Louis A., Box 433, Shreveport, La.
Bartram, John G., Midwest Refining Co., Casper, Wyo.
Bass, Nathan W., U.S. Geol. Survey, Lawrence, Kan.
Bateman, Alan M., Drawer C., Yale Station, New Haven, Conn.
Bates, Mowry, Lindsay, Calif.
Bauer, C. Max, Midwest Refining Co., Box 972, Amarillo, Tex.
Beal, Carl H., 200 Bush St., San Francisco, Calif.
Bean, Ward C., Box 1092, Wichita Falls, Tex.
Beck, Elfred, Box 1020, Producers & Refiners Corp., Patterson Bldg., Denver, Colo.
Becker, Clyde M., 1203 S. Sixth St., Chickasha, Okla.
Beckwith, Henry T., Box 1052, Bartlesville, Okla.
Beecher, Charles E., Empire Gas & Fuel Co., Bartlesville, Okla.
Beede, J. W., 1201 S. David St., San Angelo, Tex.
Beekly, Albert L., Box 2025, Tulsa, Okla.
Bell, Harry W., Division of Minerals, Dept. of Conservation, Shreveport. La.
Bell, John, International Petroleum Co., Apartado 162, Tampico, Mexico
Bending, Ralph E., Box 592, Eureka, Kan.
Bendrat, Thomas A. 203 West Jones St., Savannah, Ga.
Bennett, Clyde M., Louisiana Oil Refining Corp., First National Bank Bldg., Shreveport, La.

Benton, Louis B., Humble Refining Co., Box 285, Mabank, Tex.
Berger, Walter R., Box 1659, Fort Worth, Tex.
Bernard, W. E. Box 2044, Tulsa, Okla.
Bernoulli, Walter, 48 Place de Meir, Antwerp, Belgium
Best, J. Boyd, 803 Second National Bank Bldg., Houston, Tex.
Bevier, George M., 708 Pecore St., Houston, Tex.
Bierman, Alfred C., 311 Southland Life Ins. Bldg., Dallas, Tex.
Birk, Ralph A., Box 299, Ardmore, Okla.
Black, Glenn W., Union Oil Company of California, Santa Fe Springs, Calif.
Blackwelder, Eliot, Stanford University, Calif.
Blake, Frank O., 520 N. Friends Ave., Whittier, Calif.
Blanchard, W. Grant, 1020 Patterson Bldg., Denver, Colo.
Blatchley, Raymond S., 924 Trust & Savings Bldg., Los Angeles, Calif.
Bleecker, Edward S., Room 711, 21 State St., New York, N.Y.
Bloesch, Edward, 440 Kennedy Bldg., Tulsa, Okla.
Bohart, Philip H., Apartado 106, Tampico, Mexico
Bonine, C. A., Dept. of Geol., Pennsylvania State College, State College, Pa.
Bontz, Conrad K., 235 Middlefield Road, Palo Alto, Calif.
Borden, S. P., 717 Ardis Bldg., Shreveport, La.
Bossler, Robert B., Chemical Oil & Gas Co., 815 Union Bank Bldg., Pittsburgh, Pa.
Bostick, J. Wallace, Stoneleigh Court, Dallas, Tex.
Bosworth, Thomas O., 12 St. Giles St., Northampton, England
Bowen, Charles F., Room 1560, 26 Broadway, New York City
Bowen, James P., Panhandle Refining Co., Wichita Falls, Tex.
Bowes, Glenn H., 175 May Ave., Monrovia, Calif.
Bowman, Wayne F., 1416 Waverly St., Houston, Tex.
Boyd, Harold E., Henry Doherty & Co., 60 Wall St., New York City
Boylan, Ebert E., Room 711, 21 State St., New York City
Boyle, Albert C., Jr., 162 N. Ninth St., Laramie, Wyo.
Brace, Orval L., 732 Giddens-Lane Bldg., Shreveport, La.
Bradish, Ford, W. Sixth St., Breckenridge, Tex.
Brainerd, Arthur E., 2333 Albion St., Denver, Colo.
Brandenthaler, Rudolph R., U.S., Bureau of Mines, Bartlesville, Okla.
Branner, George C., State Capitol Bldg., Little Rock, Ark.
Branson, E. B., 301 S. Glenwood Ave., Columbia, Mo.
Brantly, John E., Atlantic Refining Co., Philadelphia, Pa.
Brauchli, Rud., Anderson-Prichard Oil Corp., Colcord Bldg., Oklahoma City, Okla.
Bremner, Carl St. J., 1808 Monterey Ave., Berkeley, Calif.
Brokaw, Dr. Albert D., 157 Maplewood Ave., Maplewood, N.J.
Broman, Isidore J., Box 440, Round Rock, Tex.
Brown, E. Call, 921 Security Bldge., Los Angeles, Calif.

Brown, Harry J., 1111 South Elgin St., Tulsa, Okla.
Brown, Ira Otho, 101½ Lewis St., San Antonio, Tex.
Brown, J. Earle, Tidal Oil Co., 2005 W. T. Waggoner Bldg., Fort Worth, Tex.
Brown, Robert W., 4253 Gladys Ave., Chicago, Ill.
Brown, Vergil N., % J. Stanley Brown, 328 Augusta Ave., De Kalb, Ill.
Browning, Iley B., Box 126, Ashland, Ky.
Bruyere, Alan, Box 491, Cisco, Tex.
Bryan, Barnabas, Room 1414, 42 Broadway, New York, N.Y.
Bryan, Frank, address unknown
Buehler, H. A., Rolla, Mo.
Bullard, Edgar F., Dixie Oil Co., 332 Harvey Snider Bldg., Wichita Falls, Tex.
Bullard, Fred M., 903 W. Twenty-second St., Austin, Tex.
Burg, Robert S., 419 W. T. Waggoner Bldg., Fort Worth, Tex.
Burling, Lancaster D., Vassar College, Poughkeepsie, N.Y.
Burnett, Jerome B., Apartado 172, Lago Petroleum Corp., Maracaibo, Venezuela, S.A.
Burress, Walter M., 1106 F. & M. Bank Bldg., Fort Worth, Tex.
Burt, Roy A., 309 Land Bank Bldg., Kansas City, Mo.
Burton, George E., Box 58, Ardmore, Okla.
Burtt, John G., 303 Higgins Bldg., Los Angeles, Calif.
Bush, Reed D., State Mining Bureau, Ferry Bldg., San Francisco, Calif.
Butcher, Seldon D., Marland Refining Co., Geol. Dept., Ponca City, Okla.
Butters, Roy M., 327 E. Park Ave., San Antonio, Tex.
Butterworth, E. M., Room 1625, 225 Bush St., San Francisco, Calif.
Buttram, Frank, 601 W. Fourteenth St., Oklahoma City, Okla.
Buttram, Wm. A., 721 Braniff Bldg., Oklahoma City, Okla.
Bybee, H. P. 509 Rust Bldg., San Antonio, Tex.
Bybee, H. P., 509 Rust Bldg., San Angelo, Tex.

Cadman, Wilson K., Box 224, Eureka, Kan.
Callahan, Drury V., 207 Simpson Bldg., Atlantic Oil Prod. Co., Ardmore, Okla.
Calvert, W. R., 512 Detwiler Bldg., Los Angeles, Calif.
Campbell, Erroll P., U.S. Bureau of Mines, Bartlesville, Okla.
Campbell, Harry A., 541 Harvey-Snyder Bldg., Wichita Falls, Tex.
Campbell, Marius R., U.S. Geol. Survey, Washington, D.C.
Campbell, Robert B., Box 537, San Angelo, Tex.
Carlson, Charles G., 725 South Cincinnati St., Tulsa, Okla.
Carlton, Dave P., 908 Humble Bldg., Houston, Tex.
Carney, Frank, Box 1031, Tulsa, Okla.
Carpenter, Everett, Mississippi Valley Oil Co., Box 607, Bartlesville, Okla.
Carpenter, M. E., 1109 Colcord Bldg., Oklahoma City, Okla.
Carr, Raymond M., Sinclair Oil & Gas Co., Box 518, Covington, Okla.
Case, J. B., 1126 Sun Finance Bldg., Los Angeles, Calif.

Case, William B., Box 1162, Roxana Petroleum Corp., Tulsa, Okla.
Cashin, D'Arcy M., 321 Humble Bldg., Houston, Tex.
Caudill, Samuel J., 1014 Atlas Life Bldg., Tulsa, Okla.
Cave, Harold S., Texas Production Co., Box 2100, Denver, Colo.
Cavins, O. A., 1502 Cortez St., Laredo, Tex.
Chapin, Theodore, Apartado 1388, Tampico, Mex.
Chase, James L., Box 583, Long Beach, Calif.
Cheda, Gilbert E., 209 W. Sixth St., Midtex Motor Co., Austin, Tex.
Cheney, Charles A., 329 Ritz Bldg., Tulsa, Okla.
Cheney, M. G., Box 65, Graham, Texas
Chevalier, Jerome A., 602 Exchange National Bank Bldg., Tulsa, Okla.
Cheyney, Alvin E., Box 45, Eureka, Kans.
Christie, Laurence G., 543 First National Bank Bldg., Houston, Tex.
Christner, Drue D., 5th Floor, Central National Bank Bldg., San Angelo, Tex.
Clapp, Frederick G., 30 Church St., Suite 2025. New York, N.Y.
Clark, Chester C., 909 Giddens Lane Bldg., Shreveport, La.
Clark, Clifton W., 710 City National Bank Bldg., Wichita Falls, Tex.
Clark, Frank R., Mid-Kansas Oil & Gas Co., 723 Petroleum Bldg., Tulsa, Okla.
Clark, Frank T., 424 Seneca St., Bartlesville, Okla.
Clark, Glenn C., Marland Refining Co., Ponca City, Okla.
Clark, Howard, Black-Gold Producing Co., 818 Kennedy Bldg., Tulsa, Okla.
Clark, Robert W., 217 Commerce Bldg., Okmulgee, Okla.
Clark, Stuart K., Marland Refining Co., Ponca City, Okla.
Clark, William L., Phillips Petroleum Co., Bartlesville, Okla.
Clarke, Carl W., 6th Floor, Mid-Continent Bldg., Tulsa, Okla.
Classen, Willard J., Box 392, R.F.D., Menlo Park, Calif.
Cline, Justus H., Derby Oil Co., Wichita, Kansas.
Clinkscales, Albert S., 518 Clinton Bldg., Tulsa, Okla.
Closuit, E. M., 2011 Lucile St., Wichita Falls, Tex.
Clowe, Charles E., Box 417, Ardmore, Okla.
Coats, Charles M., Lion Oil Refining Co., Drawer Y, El Dorado, Ark.
Coleman, Bond, Mound City, Kan.
Collingwood, Douglas M., Sun Oil Co., Box 1109, Dallas, Tex.
Collins, Melvin J., 425 Williams St., Denver, Colo.
Collom, Roy E., 920 Fresno Ave., Berkeley, Calif.
Condit, D. Dale, Whitehall Petroleum Corp. Ltd., Bamboo Villa, Shillong, Assam, India
Conkling, R. A., 1109 Colcord Bldge., Oklahoma City, Okla.
Cook, Harold J., Agate, Nebraska
Cooper, Herschel H., 610 Rigsby Ave., San Antonio, Tex.
Copley, Ralph D., Standard Oil Co. Producing Dept., Box 487, Inglewood, Calif.
Copp, William W., 512 A. G. Bartlett Bldg., Los Angeles, Calif.

Corbett, Clifton S., 217 N. Kansas St., Edwardsville, Ill.
Coryell, Lewis S., 337 W. Fifth St., Bristow, Okla.
Cotulla, Reuben E., 1710 F. & M. Bank Bldg., Forth Worth, Tex.
Crandall, Hector, 345 Kennedy Bldg., Tulsa, Okla.
Crandall, Roderic, Baxter Estates, Port Washington, Long Island, N.Y.
Crebbs, Chester M., Apartado 234 ,Maracaibo, Venezuela, S.A.
Crider, A. F., 821 Ontario St., Shreveport, La.
Crook, Theodore H., 395 Seventh St., Beaumont, Tex.
Crooks, Harold F., 4 Rue Herran, Paris (XVI), France
Crum, Harry E., 317 W. Cheyenne Road, Colorado Springs, Colo.
Cullen, John, Drawer 1267, Marland Refining Co., Ponca City, Okla.
Cullen, Tom J., U.S. Bureau of Mines, Casper, Wyo.
Culver, Harold E., State College of Washington, Pullman, Wash.
Cumming, Alfred, Box 1403, Tulsa, Okla.
Cunningham, George M., 217 W. Whiting St., Fullerton, Calif.
Curtice, A. Arthur, 1035 A. G. Bartlett Bldg., 215 W. Seventh St., Los Angeles, Calif.
Cushman, Joseph A., 76 Brook Road, Sharon, Mass.
Cutler, Willard W., Jr., Room 31, Seventh & Alvarado Bldg., Los Angeles, Calif.

Dalburg, Frank A., Montoursville, Pa.
Dallas, Orlan L., 1403 E. Seventeenth Place, Tulsa, Okla.
Dally, Claude F., 611 Petroleum Bldg., Tulsa, Okla.
Dannenberg, Richard M., Roxana Petroleum Corp., 927 Mayo Bldg., Tulsa, Okla.
Darnell, James L., 170 Broadway, New York City
Davies, Fred A., Box 1304, Billings, Montana
Davis, Elmer F., 417 E. Randolph St., Glendale, Calif.
Davis, Ralph E., 1710 Union Bank Bldg., Pittsburgh, Pa.
Davis, Robert J., Box 1162, Tulsa, Okla.
Davis, Thornton, Box 949, Wichita Falls, Tex.
Dawson, Joseph M., Box 564, San Antonio, Tex.
Day, Clarence O., 625 Slattery Bldg., Phillips Petroleum Co., Shreveport, La.
Dean, David, 2823 E. Fifth St., Tulsa, Okla.
Dean, Paul, 2823 E. Fifth St., Tulsa, Okla.
Decker, Charles E., 508 Chautauqua Ave., Norman, Okla.
DeGolyer, E., 65 Broadway, New York City
De Loys, Francois, 5230 Sunset Blvd., Los Angeles, Calif.
Denison, A. R., Box 2022, Tulsa, Okla.
Deussen, Alexander, 1917 Post-Dispatch Building, Houston, Tex.
DeWolf, Frank W., 3502 Audubon Place, Houston, Tex.
Dickerson, Roy E., 225 Bush St., San Francisco, Calif.

Dickie, W. E., 324 W. Lockwood Ave., Webster Groves, Mo.
Dissinger, Earl, Apartado 1390, Tampico, Mexico
Dixon, A. Faison, Room 2229, 120 Broadway, New York City
Dobbin, Carroll E., U. S. Geol. Survey, Washington, D.C.
Dodge, William E., 315 W. Highland Ave., Shawnee, Okla.
Dodson, Floyd C., Ricker & Dodson, San Angelo, Tex.
Dolman, Phil B., 306 National Bank of Commerce Bldg., Tulsa, Okla.
Donnelly, L. G., 428 Canon Road, Santa Fe, New Mexico
Donoghue, David, Texas Pacific Coal & Oil Co., Fort Worth, Tex.
Donovan, Percy W., 710 Security Bldg., Minneapolis, Minn.
Dorchester, Charles M., Box 107, Gulf Refining Co., Shreveport, La.
Dorsey, George E., Box 411, Tulsa, Okla.
Dott, Robert H., Box 2045, Tulsa, Okla.
Doub, Charles O., Box 413, Graham, Tex.
Douglas, James M., Union Oil Company of California, Box 571, Fort Collins, Colo.
Dovre, Adolph O., 704 W. Seventh St., Cisco, Tex.
Drake, N. F., Fayetteville, Ark.
Dreher, Dr. Otto, Apartado 150, Tampico, Mexico
Dresser, Myron A., Room 719, Avenida Roque Saenz Pena 567, Buenos Aires, Argentina, S.A.
Driver, Herschel L., 1936 S. Harcourt Ave., Los Angeles, Calif.
Duce, James T., A. C. Hunter, The Texas Co., 17 Battery Place, New York City
Dumble, E. T., R.F.D. Box 55, Tunstall, Va.
Dunlap, Gilmore S., Schaffer Oil Co., 729 Kennedy Bldge., Tulsa, Okla.
Dunlevy, Robert B., 302 College St., Winfield, Kan.
Duston, Arthur W., Independent Oil & Gas Co., Tulsa, Okla.

Eastman, Walter F., W. B. Eastman, Bethel, Conn.
Easton, H. D., Suite 305, Ardis Bldg., Shreveport, La.
Eaton, Clayton H., 408 City National Bank Bldg., Wichita Falls, Tex.
Eaton, Joseph E., Room 31, 2033 W. Seventh St., Los Angeles, Calif.
Ebmeyer, Gerard E., 321 South C St., Arkansas City, Kan.
Eby, J. Brian, 543 First National Bank Bldg., Houston, Tex.
Eckert, Frank E., Hanley & Bird, Bradford, Pa.
Eckes, Charles R., 1240 South Newport, Tulsa, Okla.
Edson, Dwight J., Box 28, Corsicana, Tex.
Edson, Mrs. Fanny C., Box 1162, Roxana Petroleum Corp., Tulsa, Okla.
Edson, Frank, 944 Chautauqua Ave., Norman, Okla.
Edwards, Everett C., Box 1013, Colorado, Tex.
Edwards, Merwin G., The Shell Company of Calif., Higgins Bldg., Los Angeles, Calif.

Edwards, Orrin M., Red Bank Oil Co., 306 Castle Bldg., Tulsa, Okla.
Egan, John A., The Carter Oil Co., Box 2045, Tulsa, Okla.
Eichelberger, Orion H., 606 Pujo St., Lake Charles, La.
Eirich, Constance A., Box 2044, Tulsa, Okla.
Ekblaw, W. Elmer, No. 6 Woodbine St., Worcester, Mass.
Elledge, Emmett R., Phillips Petroleum Co., Breckenridge, Tex.
Elledge, George A., 703 Dumble St., Houston, Tex.
Elliott, George Reginald, 605 West 10th Street, Los Angeles, Calif
Elliott, John E., 903 Wright & Callender Bldg., Los Angeles, Calif.
Ellis, George L., 734 Kennedy Bldg., Tulsa, Okla.
Ellisor, Alva C., 903 Humble Bldg., Houston, Tex.
Ely, Fred B., Room 1560, 26 Broadway, New York, N.Y.
Emery, Wilson B., 2135 Fourth St., Boulder, Colo.
Emmons, William H., University of Minnesota, Minneapolis, Minn.
Emrick, Eggleston B., 3100 Connecticut Ave., Apartment 216, Washington, D.C.
Engel, Rene L. H., Dept. of Geol., Calif. Institute of Technology, Pasadena, Calif.
English, Leon E., 806 Euclid Ave., Lawton, Okla.
English, Walter A., Standard Oil Co., Taft, Calif.
Erb, Josef T., Oldenbarneveltl ig., The Hague, Holland
Erni, Dr. Arthur, Villa Kully, Trimbach, Kt. Solothurn, Switzerland
Estabrook, Edward L., Pan-American Exploration Co., 120 Broadway, New York City
Evans, Noel, Marland Refining Co., Ponca City, Okla.
Evans, Oren F., 810 Monnett St., Norman, Okla.
Eyl, W. C., Nicholasville Road, Lexington, Ky.
Eyssell, Alfred R., 503 Central National Bank Bldg., San Angelo, Tex.

Fath, A. E., Vacuum Oil Co., 61 Broadway, New York City
Fees, Leon V., Continental Oil Co., Patterson Bldg., Denver, Colo.
Ferguson, John L., Box 499, Cisco, Tex.
Ferguson, R. N., 526 A. G. Bartlett Bldg., Los Angeles, Calif.
Fettke, Charles R., 1118 Wightman St., Pittsburgh, Pa.
Filmer, Edwin A., 50 Conklin Ave., Binghamton, N.Y.
Finch, Elmer H., Box 275, Smithville, Tex.
Finch, John Wellington, 707 First National Bank Bldg., Denver, Colo.
Finley, D. D., 1018 Atlas Life Bldg., Tulsa, Okla.
Fischer, Dr. Otto, Box 1375, Charleston, West Va.
Fisher, Cassius A., 711 First National Bank Bldg., Denver, Colo.
Floyd, Florin W., Box 2045, Tulsa Okla.
Fohs, F. Julius, 51 E. Forty-second St., New York City
Foley, Lyndon L., 724 N. Denver St., Tulsa, Okla.

Folger, Anthony, 2715 Claremont Blvd., Berkeley, Calif.
Ford, Carl S., Garber Bros., Inc., Box 143, Enid, Okla.
Forrester, George A., 251 S. Rutan, Wichita, Kan.
Foster, F. K., Box 314, Wichita Falls, Tex.
Foster, Walter L., University of Tulsa, Tulsa, Okla.
Foster, William H., 314 Atlas Bldg., Tulsa, Okla.
Fowler, Charles North, Jr., Box 508, Eagle Pass, Tex.
Fowler, George M., University Club, Salt Lake City, Utah
Franklin, Louis, 2310 Seventh St., Wichita Falls, Tex.
Freedman, Louis H., 427 Cotton Exchange Bldg., Marland Rfg. Co., Houston, Tex.
Frei, Frederick, Roxana Petroleum Corp., Dallas, Tex.
Frey, Alfred P., Cia "La Corona," Apartado 238, Tampico, Mexico
Froyd, Erwin A., Salt Creek, Wyo.
Fuqua, H. B., Box 988, Wichita Falls, Tex.
Fyfe, Douglas, 215 W. Seventh St., Los Angeles, Calif.

Galbraith, Thomas J., 225 Bush St., San Francisco, Calif.
Gale, Hoyt S., 1775 Hill Drive, Eagle Rock, Los Angeles, Calif.
Galloway, Dr. Jesse J., Columbia University, Geol. Dept., New York City
Galpin, S. L., 630 Park Drive, Ames, Iowa
Ganz, Ernst, Postal Casilla No. 9, Paita, Northern Peru, S.A.
Gardner, James H., 505 Exchange National Bank Bldg., Tulsa, Okla.
Garfias, Valentine R., H. L. Doherty & Co., 60 Wall St., New York City
Garner, Aubrey H., 120 Broadway, New York City
Garnjost, Frederick W., Box 81, Shreveport, La.
Garrett, Lovic P., 4301 Rossmoyne Blvd., Houston, Tex.
Garrett, Melvin M., 233 Harvey-Snider Bldg., Wichita Falls, Tex.
Garrett, Robert E., 902 Petroleum Bldg., Tulsa, Okla.
Garrett, S. G., 302 Atlas Life Bldg., Tulsa, Okla.
Gartner, James L., Box 1748, Tulsa, Okla.
Gawthrop, R. M., Prairie Oil & Gas Co., Geol. Dept. Tulsa, Okla.
Gaylord, E. G., 79 New Montgomery St., San Francisco, Calif.
Geis, Wilfrid H., Box 605, Casper, Wyo.
George, H. C., Faculty Exchange, Box 83, Norman, Okla.
George, William O., 560 Avenida de Mayo, Buenos Aires, Argentina, S.A.
Gerst, G. E. Mathijsen, Compania Mexicana El Aguila, Puerto Mexico, Mexico
Gester, George C., 1120 Standard Oil Bldg., San Francisco, Calif.
Gester, Stephen H., 1120 Standard Oil Bldg., San Francisco, Calif.
Getzendaner, Frank M., Uvalde, Tex.
Geyer, F. Park, Marland Oil Co., Box 1658, Fort Worth, Tex.
Giffin, Wilson C., 1003 Higgins Bldg., Los Angeles, Calif.

Giles, Albert W., Dept. of Geol., University of Arkansas, Fayetteville, Ark.
Gillan, Silas L., 1022 Stock Exchange Bldg., Los Angeles, Calif.
Glenn, L. C., 2111 Garland Ave., Nashville, Tenn.
Goldston, Walter L., Jr., 206 Magnolia Bldg., Dallas, Tex.
Goodrich, Harold B., 1628 S. Cincinnati, Tulsa, Okla.
Goodrich, Robert D., 818 Ogden St., San Antonio, Tex.
Gordon, Dugald, 2914 San Jacinto St., Houston, Tex.
Gordon, Wallace, Gordon Home Place, Azusa, Calif.
Goudkoff, Paul P., 2033 W. Seventh St., Los Angeles, Calif.
Gouin, Frank, Box 293, Harry Hanbury, Duncan, Okla.
Gould, Charles N., Oklahoma Geol. Survey, Norman, Okla.
Graham, Edwin S., Graham, Tex.
Grant, U. S., Northwestern University, Evanston, Ill.
Gray, Alfred, Atlantic Producing Co., Dallas, Tex.
Green, Darsie A., Box 952, Shawnee, Okla.
Green, George L., The Atlantic Co., 260 S. Broad St., Philadelphia, Pa.
Greene, Frank C., 1434 South Cincinnati, Tulsa, Okla.
Gretzinger, William, 1009 Davis Ave., Pittsburgh, Pa.
Griley, H. L., 3299 Broadwell Ave., Cincinnati, Ohio.
Grimm, Maurice W., 315 Ward Bldg., Shreveport, La.
Griswold, Clyde T., 545 Pecos Ave., Raton, New Mexico
Gulley, M. Gordon, Marland Oil Co., Ponca City, Okla.
Gunter, Herman, 715 E. Virginia St., Tallahassee, Fla.

Hagan, Arthur M., Box 1520, Transcontinental Oil Co., Fort Worth, Tex.
Hageman, Donald E., Queen City Oil Co., Kevin, Montana
Hager, Dilworth S., Drawer C, Houston, Tex.
Hager, Lee, 504 West Bldg., Houston, Tex.
Hake, Benjamin F., 1342 Middlefield Road, Palo Alto, Calif.
Hall, Ellis A., Pan-American Petroleum Transport Co., 120 Broadway, New York City
Hall, Elwin B., 886 S. Bronson Ave., Los Angeles, Calif.
Hall, Roy H., Box 1144, Wichita, Kan.
Hamilton, Charles W., Room 711, 21 State St., New York, N.Y.
Hamilton, W. R., 1325 South Boston Ave., Tulsa, Okla.
Hammer, Alva A., Absaroka Oil Development Co., 502 Securities Bldg., Billings, Mont.
Hammill, Chester A., 1417 American Exchange Bank Bldg., Dallas, Tex.
Hance, James H., College Station, Tex.
Hanna, G. Dallas, California Academy of Sciences, San Francisco, Calif.
Hanna, Marcus A., 4422 Clay St., Houston, Tex.
Hardison, Harvey, Box 212, Coalinga, Calif.
Hares, Charles J., 305 Franklin St., Denver, Colo.

Harkness, Robert B., 5 Queens Park, Toronto, Ont., Canada.
Harlowe, Leslie S., Box 1117, Louisiana Oil Refining Co., Shreveport, La.
Harnsberger, T. K., Box 1162, Roxana Petroleum Corp. Tulsa, Okla.
Harper, Oliver C., Gulf Production Co., San Angelo, Tex.
Harrington, Geo. L., 567 Ave. Saenz Peña, Standard Oil Co., Buenos Aires, Argentina, S.A.
Harrison, Thomas S., 705 First National Bank Bldg., Denver, Colo.
Hartley, Burton, Box 981, Cisco, Tex.
Hartman, Adolph E., 412 Travis Bldg., San Antonio, Tex.
Haury, P. S., Box 3163, Taft, Calif.
Hawley, Henry J., 225 Bush St., San Francisco, Calif.
Hawley, James E., 433 W. Gilman St., Madison, Wis.
Haworth, Erasmus, 1503 Massachusetts St., Lawrence, Kan.
Haworth, Huntsman, 425 N. Atchinson St., Eldorado, Kan.
Hay, Laurence C., Skelly Oil Co., Eldorado, Kan.
Hayes, Albert O., Dept. of Geology, Lafayette College, Easton, Pa.
Hayes, Allan S., 1003 Higgins Bldg., Los Angeles, Calif.
Hayes, Reese L., 256 Harvey-Snider Bldg., Wichita Falls, Tex.
Haynes, Winthrop P., 82 avenue des Champs Élysées, Paris, France
Hazeltine, R. S., Dee, Ore.
Headley, Joseph B., Jacobson Apartments, Roswell, N.M.
Heald, Kenneth C., Box 1214, Gulf Refining Co., Pittsburgh, Pa.
Heaton, R. L., 2374 Elm St., Denver, Colo.
Heidenreich, W. Lee, 216 Seventeenth St., Santa Monica, Calif.
Henderson, Charles W., 409 New Postoffice Bldg., Denver, Colo.
Henderson, Junius 1305 Euclid Ave., Boulder, Colo.
Henderson, Paul LeRoy, 521 Standard Oil Bldg., Los Angeles, Calif.
Hendon, Bryan, 1129 North Beard St., Shawnee, Okla.
Hendrichs, W. Th. M., Bataafsche Petr. Mpy. Balik, Papan, East Borneo, D.E.I.
Hendricks, John A., Apartado 1385, Tampico, Mexico
Hendrickson, Victor J., 1703 Williams St., Denver, Colo.
Henley, A. S., 1106 Scanlan Bldg., Houston, Tex.
Hennen, Ray V., Transcontinental Oil Co., Tulsa, Okla.
Henniger, Waldemar F., 1109 California Ave., Houston, Tex.
Henning, John L., 525 Kirby St., Lake Charles, La.
Henny, Gerhard, Shell Company of California, Higgins Bldg., Los Angeles, Calif.
Henry, Wm. Wirt, Henry Oil Co., Tulsa, Okla.
Henson, Gurrie R., Roxana Petroleum Corp., Dallas, Tex.
Herald, Frank A., 303 Cosden Bldg., Tulsa, Okla.
Herald, J. M., 303 Cosden Bldg., Tulsa, Okla.
Herold, Stanley C., Stanford University, Calif.

Heroy, William B., 19 Wayne Ave., White Plains, N.Y.
Hertel, Francis W., Box R, Ventura, Calif.
Hiestand, Thomas C., The Pure Oil Co., Columbus, O.
Higgs, Morton T., The Sun Co., Box 1109, Dallas, Tex.
Hill, Benjamin F., Cripple Creek, Colo.
Hill, Robert T., Hotel Commodore, Los Angeles, Calif.
Hindes, E. P., Box 389, Bartlesville, Okla.
Hinds, Henry, 1153 Laurel Ave., St. Paul, Minn.
Hintze, F. F., 400 California Bldg., Denver, Colo.
Hodge, Edwin T., University of Oregon, Eugene, Ore.
Hodson, Floyd, 311 Dryden Road, Ithaca, N.Y.
Hoffer, Clarence W., 1610 Tenth St., Wichita Falls, Tex.
Hoffman, Charles C., Box 71, Eldorado, Kans.
Hoffman, Malvin G., 1619 South Newport St., Tulsa, Okla.
Holden, Roy J., Polytechnic Institute, Blacksburg, Va.
Holden, William J., Box 216, Camden, Ark.
Holl, Frederick G., Box 104, Eldorado, Kan.
Holloman, Roy, 230 Steel Bldg., Denver, Colo.
Holman, Eugene, 616 Giddens Lane Bldg., Shreveport, La.
Honess, Charles W., 709 Masonic Bldg., Bartlesville, Okla.
Hoover, James E., 329 Atco Bldg., Tulsa, Okla.
Hopkins, Edwin B., Room 951, 25 Broadway, New York City
Hopkins, M. J., Rolling Bay, Bainbridge Island, Wash.
Hopkins, Oliver B., Imperial Oil Co., 56 Church St., Toronto, Canada
Hopper, Walter E., Southwestern G. & E. Co., Box 1106, Shreveport, La.
Hotchkin, Harry, 504 South Cincinnati St., Tulsa, Okla.
Housh, C. N., Drawer C, Houston, Tex.
Howard, Arthur H., Conservative Club, St. James St., London, England
Howe, Henry V., Dept. of Geol., Louisiana State University, Baton Rouge, La.
Howe, James V., 809 Peck Ave., San Antonio, Tex.
Howell, Jesse V., Box 1428 Wichita Falls, Tex.
Howell, William F., Box 1169, Marland Oil Co. of Colorado, Denver, Colo.
Hoyt, William V., 508 W. Ninth St., Cisco, Tex.
Hubbard, Wm. E., Box 1034, Wichita Falls, Tex.
Hudson, Frank S., 417 South Wilton Place, Los Angeles, Calif.
Hudson, William A., P.O. Drawer 368, San Angelo, Tex.
Hughes, C. Don, Box 148, Duncan, Okla.
Hughes, Donald D., 439 Lincoln Ave., Palo Alto, Calif.
Hughes, Richard, Burke-Greis Oil Co., Box 262, Tulsa, Okla.
Hughes, Urban B., Floral Heights Apts., Apt. T, Wichita Falls, Tex.
Hughes, V. H., 406 Exchange National Bank Bldg., Tulsa, Okla.
Huguenin, Emile, 1126 Sun Finance Bldg., Los Angeles, Calif.
Hulin, Carlton D., 1711 Central Ave., Alameda, Calif.

Hull, Joseph P.D., Box 1117, Louisiana Oil Refining Corp., Shreveport, La.
Hummel, E. W., % G. W. Hummel, Mountain View, Okla.
Hummel, Henry L., Box 1116, Wichita, Kan.
Hunter, Dresden B., Phillips Petroleum Co., Bartlesville, Okla.
Huntley, Louis G., 505 Frick Bldg., Pittsburgh, Pa.
Huntley, Stirling, 505 Frick Bldg., Pittsburgh, Pa.
Hutchinson, Frederick M., 803 Second National Bank Bldg., Houston, Tex.
Hutchinson, L. L., 510 Daniel Bldg., Tulsa, Okla.
Hyde, Clarence E., vice-president, Marland Oil Company of Texas, 1803 W. T. Waggoner Bldg., Fort Worth, Tex.
Hynes, Dibrell P., 1519 Davis St., Evanston, Ill.

Ickes, Eugene, L., 10463 Tennessee Ave., Sawtelle, Calif.
Iddings, Arthur, Geol. Dept., London & Pacific Petroleum Co., Negritos, Talara, Peru, S.A.
Iki, Tsunenaka, Mining Dept., Imperial University of Tokyo, Tokyo, Japan
Imbt, Robert F., The Pure Oil Co., San Angelo, Tex.
Irwin, Joseph S., 581 Humboldt St., Denver, Colo.
Ivy, John S., 1100 City Bank Bldg., Shreveport, La.

Jeffreys, Geoffrey, 80 Maiden Lane, New York City
Jenkins, J. H., Tidal Oil Co., W. T. Waggoner Bldg., Fort Worth, Tex.
Jensen, Joseph, 766 Pacific Electric Bldg., Los Angeles, Calif.
Johnson, Frederick A., Anchor Oil & Gas Co., Sheffield, Pa.
Johnson, Harry R., 1101 Stock Exchange Bldg., Los Angeles, Calif.
Johnson, Roswell H., 1039 Murrayhill Ave., Pittsburgh, Pa.
Johnston, Duncan McA., Room 471, 79 New Montgomery St., San Francisco, Calif.
Jones, Coy B., Godley Oil & Gas Co., 809 Amer. Exch. Bank, Dallas, Tex.
Jones, Edward L., Jr., Box 1263, Ponca City, Okla.
Jones, J. Claude, University of Nevada, Reno, Nev.
Jones, James J., 328 North Xenophon Ave., Tulsa, Okla.
Jones, Richard A., 703–4 Travis Bldg., San Antonio, Tex.
Judson, Sidney A., 1318 Marshall Ave., Houston, Tex.
Justice, Philip S., The Sun Co., Drawer 790, Beaumont, Tex.

Kaufmann, Godfrey F., Apartado 150, Tampico, Mexico
Kautz, Archie R., Box 1692, The Empire Co., Wichita Falls, Tex.
Kay, Fred H., Pan-American Explor. Co., 120 Broadway, New York, N.Y.
Keeler, Clifton M., 618 Waggoner Bldg., Wichita Falls, Tex.
Keeler, William W., 701 Atlas Life Bldg., Tulsa, Okla.
Keeley, L. C., Apartado 106, Tampico, Mexico
Kellum, Lewis B., Apartado 657, Tampico, Mexico
Kemp, James F., Schemmerhorn Hall, Columbia University, New York City

Kendrick, Frank E., Lone Star Gas Co., Dallas, Tex.
Kennedy, Luther E., 404 Atlas Life Bldg., Tulsa, Okla.
Kennedy, William, 2909 South Jennings Ave., Fort Worth, Tex.
Kent, Joseph T., I.T.U., Bureau of Internal Revenue, Engineering Div., 20th and C Sts., Tempo No. 5, Washington, D.C.
Keppler, Leo G., Box 641, Tulsa, Okla.
Kernan, Thomas H., Ricker & Dodson Bldg., 24½ Chadbourne St., San Angelo, Tex.
Kerr, John B., 601 Balboa Bldg., San Francisco, Calif.
Kesler, L. W., 1305 E. Ninth Ave., Winfield, Kan.
Kew, Wm. S. W., Standard Oil Co., Box 1390, Station C., Los Angeles, Calif.
Kimball, Kent K., Mid-Kansas Oil Co., Tulsa, Okla.
King, Vernon L., 804 Hillstreet Bldg., Los Angeles, Calif.
Kinkel, John F., Wakeeney, Kan.
Kinkel, William C., Box 477, Albany, Tex.
Kirby, Grady, Box 564, San Antonio, Tex.
Kirk, Charles T., Box 1592, Tulsa, Okla.
Kirwan, Matthew J., 1417 Dewey Ave., Bartlesville, Okla.
Kite, William C., 704 Braniff Bldg., Oklahoma City, Okla.
Kitson, Howard W., The Shell Company of California, 424 Higgins Bldg., Los Angeles, Calif.
Kleinpell, William D., Room 1015, 200 Bush St., San Francisco, Calif.
Klingaman, George L., 225 Bush St., San Francisco, Calif.
Knapp, Arthur, Box 1902, Philadelphia, Pa.
Knappen, Russell S., Dept. of Geol., Harvard University, Cambridge, Mass.
Kniker, Hedwig T., Ricker & Dodson, San Angelo, Tex.
Knox, John K., Phillips Petroleum Co., Bartlesville, Okla.
Kobayashi, Giichiro, 310 Zoshigaya, Tokyo-fuka, Japan
Kolm, Robert N., Atlantic Producing Co., Box 1037, Wichita Falls, Tex.
Koto, B., Geological Institute, University of Tokyo, Tokyo, Japan
Krampert, E. Walter, 3020 House St., Cheyenne, Wyo.
Kraus, Edgar, 102 North Kentucky Street, Roswell, New Mexico
Kruisselbrink, J. W., 114 Noorder Amstellaan, Amsterdam, Holland

La Croix, Morris F., 82 Devonshire St., Boston, Mass.
Lahee, Frederic H., Box 1109, The Sun Co., Dallas, Tex.
Laird, B. L., The California Co., Drawer 846, Colorado, Tex.
Lake, Francis W., Union Oil Co., Brea, Calif.
Lane, Alfred C., 22 Arlington St., Cambridge B., Mass.
LaNeve, R. O., 415 N. West Second St., Mineral Wells, Tex.
Lang, Walter B., U. S. Geol. Survey, Midland, Tex.
Langworthy, A. A., The Pure Oil Co., Tulsa, Okla.
Larkin, Pierce, 1440 S. Norfolk St., Tulsa, Okla.

Larrazolo, Octaviano A., Jr., Apartado 94, Huasteca Petr. Co., Tampico, Mexico
Larsh, Walter W., 515 Wheeler-Kelly-Hagny Bldg., Wichita Falls, Tex.
Laskey, Glenn E., Box 1092, Wichita Falls, Tex.
Lasky, Bernard H., 906 Atlas Life Bldg., Tulsa, Okla.
Lauer, Arnold W., Box 1429, Eastern Oil Co., Tulsa, Okla.
Laves, Ulrich R., Box 267, Coleman, Tex.
Leach, Thomas W., Transcontinental Oil Co., Box 2064, Tulsa, Okla.
Lee, Marvin, 312 N. Clifton Ave., Wichita, Kan.
Lee, Wallace, Box 72, Pecos, Tex.
Leibensperger, Raymond, Apartado 657, Tampico, Mexico
Leighton, Morris M., Illinois Geol. Survey, Urbana, Ill.
Lemley, G. C., Box 1911, Superior Oil Corp., Tulsa, Okla.
Lepper, G. W., The Burmah Oil Co., Ltd., Nyounghla, Magwe District, Upper Burma, India
Lesniak, Stanislaw, Apartado 86, Puerto Mexico, Ver, Mexico
Levorsen, A. Irving, Gypsy Oil Co., Box 127, Okmulgee, Okla.
Lewis, Frank E., Delmar Oil Co., 32 Fuqua Bldg., Amarillo, Tex.
Lewis, James O., 938 Kennedy Bldg., Tulsa, Okla.
Lewis, J. Volney, Rutgers College, New Brunswick, N.J.
Lewis, J. Whitney, Box 383, Cisco, Tex.
Ley, Henry A., 1128 S. Owasso St., Tulsa, Okla.
Liddle, Ralph A., The Pure Oil Co., Mexia, Tex.
Lilligren, J. M., Box 201, Garnett, Kan.
Lindeblad, E. E., 709 New Masonic Bldg., Bartlesville, Okla.
Link, Theodore A., 616 C St., La Porte, Ind.
Lloyd, Abe Morris, The Sun Co., Box 1109, Dallas, Tex.
Lloyd, E. Russell, 1104 First National Bank Bldg., Denver, Colo.
Loel, Wayne, 1025 Stock Exchange Bldg., Los Angeles, Calif.
Logan, Clarence Z., Engineering Div., I.T.U., Bureau of Internal Revenue, 20th and C Sts., Tempo No. 5, Washington, D.C.
Logan, David M., Okmulgee, Okla.
Long, Carl T., Standard Oil Co., Drawer J, Whittier, Calif.
Longmire, William R., Box 2044, Tulsa, Okla.
Longyear, Robert D., 710 Security Bldg., Minneapolis, Minn.
Loomis, Harve, Box 510, Ardmore, Okla.
Louderback, George D., University of California, Berkeley, Calif.
Lounsbery, D. E., 608 Alexander Bldg., Abilene, Tex.
Lovejoy, John M., Box 2022, Tulsa, Okla.
Lowe, Ephraim N., Mississippi Geol. Survey, University, Miss.
Luman, Edmondson D., Atlantic Oil Producing Co., 510 Commercial Bldg., Tulsa, Okla.
Lupton, Charles T., 617 Gilpin St., Denver, Colo.
Lynton, Edward D., 524 Standard Oil Bldg., Los Angeles, Calif.
Lyons, Richard T., Skelly Oil Co., Ricker-Dodson Bldg., San Angelo, Tex.

MacDonald, Donald F., 16 Eastover Court, Louisville, Ky.
MacDonnell, Erwin H., 520 Securities Bldg., Billings, Mont.
MacFadyen, William A., Longships, Capel-le-Ferne, near Folkestone, England
Mackay, Donald K., The Sun Co., American Exchange Bank Bldg., Dallas, Tex.
MacKay, Hugh, 706 South Poplar St., Sapulpa, Okla.
Mackenzie, Andrew N., 1312 Stevenson Ave., Pasadena, Calif.
Macready, George A., 300 N. Plymouth Blvd., Los Angeles, Calif.
Manning, Van H., 88 Ascan Ave., Forest Hills, N.Y.
Markham, Edmond O., Carter Oil Co., Box 2045, Tulsa, Okla.
Marquardt, Ernest, 852 N. Stanley Ave., Los Angeles, Calif.
Marsters, Vernon F., 123 Railway Exchange Bldg., Kansas City, Mo.
Marston, R. L., Beacon-Sun Oil Co., Finance Bldg, Philadelphia, Pa.
Martin, Francis I., Apartado 234, Maracaibo, Venezuela, S.A.
Martin, Frederick O., Apartado 61, Bogota, Columbia, S.A.
Martin, George C., 3126 Thirty-eighth St., Washington, D.C.
Martin, Helen M., The Carter Oil Co., Tulsa, Okla.
Mason, Shirley L., 5554 Avondale Place, Pittsburgh, Pa.
Masterson, Rebecca, 232 Marshall St., Houston, Tex.
Mather, Kirtley F., Geol. Museum, Oxford St., Cambridge, Mass.
Matson, George C., 1534 E. Seventeenth Place, Tulsa, Okla.
Matteson, Wallace G., Box 376, Center Moriches, Long Island, N.Y.
Maverick, Phillip, 132 E. Harris St., San Angelo, Tex.
May, Arthur R., Box 596, Santa Maria, Calif.
McCluer, R. D., Box 742, Corsicana, Tex.
McCollom, C. R., Union Oil Company of California, Union Oil Bldg., Los Angeles, Calif.
McCollough, A. Stafford, 729 A. G. Bartlett Bldg., Los Angeles, Calif.
McCoy, Alex W., 1020 Patterson Bldg., Denver, Colo.
McCrary, E. W., Box 790, Tidal Oil Co., Tulsa, Okla.
McCulloch, Joseph Paul, Box 1214, Pittsburgh, Pa.
McFarland, R. S., Box 1501, Twin State Oil Co., Tulsa, Okla.
McFerron, George I., 2744 E. Fifth St., Tulsa, Okla.
McGill, Andrew K., Tropical Oil Co., Apartado 170, Cartagena, Columbia, S.A.
McGirl, James N., 827 Mayo Bldg., Tulsa, Okla.
McGowan, James J., Caixa Postal 315, Loanda, Angola, Africa
McIntyre, Paul J., Phillips Petroleum Co., Bartlesville, Okla.
McKanna, Edwin A., 700 The Alameda, Berkeley, Calif.
McKee, H. Harper, 120 Broadway, New York, N.Y.
McKim, J. W., 230 First National Bank Bldg., Denver, Colo.
McLaughlin, R. P., 902 Wright & Callender Bldg., Los Angeles, Calif.
McLellan, Hiram J., Box 612, Humble Oil Co., Corsicana, Tex.
McLeod, Angus, Roxana Petroleum Corp., Simpson-Whiteman Bldg., Dallas, Tex.
McNeese, Charles H., Marland Refining Co., Ponca City, Okla.

McNutt, Vachel H., 412 Commercial Bldg., Tulsa, Okla.
McWhirt, Burr, Roxana Petroleum Corp., Box 1162, Tulsa, Okla.
Meek, Charles E., 851 Regal Road, Berkeley, Calif.
Melcher, A. F., Research Dept., Marland Oil Co., Ponca City, Okla.
Melhase, John, 671 Vincente Ave., Berkeley, Calif.
Mendenhall, Walter C., U. S. Geol. Survey, Washington, D.C.
Meredith, Carlton, Kirby Bldg., Dallas, Tex.
Merritt, Floyd C., 903 Wright & Callender Bldg., Los Angeles, Calif.
Merritt, J. W., 1324 E. Seventeenth Place, Tulsa, Oklahoma.
Milek, Andrew, Apartado 241, Mexican Sinclair Petroleum Corp., Tampico, Mexico
Millard, William J., Room 919, Harrison Bldg., Philadelphia, Pa.
Miller, Forest J., The Texas Co., Production Dept., Shreveport, La.
Miller, Guy E., 4130 Shaw St., Long Beach, Calif.
Miller, John C., Room 206, Custom House, Bureau of Mines, Denver, Colo.
Miller, Wendell Z., 636 Kennedy Bldg., Tulsa, Okla.
Miller, Willard L., 917 Braniff Bldg., Oklahoma City, Okla.
Millikan, Charles V., Box 2022, Tulsa, Okla.
Mills, R. Van A., U. S. Bureau of Mines, Washington, D. C.
Minor, H. E., Gulf Production Co., Houston, Tex.
Miser, Hugh D., Tennessee Geol. Survey, Nashville, Tenn.
Mitchell, Ralph H., 48 Nutfield Road, Thornton Heath, Surrey, England
Mix, Sidney E., 261 Dalzell St., Shreveport, La.
Monnett, V. Elvert, 123 White St., Norman, Okla.
Montgomery, James G., Jr., 308 Seneca St., Oil City, Pa.
Moody, Clarence L., Ohio Oil Co., Giddens-Lane Bldg., Sherveport, La.
Moore, Calvin T., 1011 Tradesmen's Bank Bldg., Oklahoma City, Okla.
Moore, Gilbert P., Room 719, Edificio Banca Boston, Buenos Aires, Argentina, S.A.
Moore, Raymond C., University of Kansas, Lawrence, Kan.
Moran, Robert B., 215 W. Seventh St., Los Angeles, Calif.
Morgan, D. M., 508 N. Fifth St., Ponca City, Okla.
Morgan, Frank A., Jr., 412 Security Bldg., Los Angeles, Calif.
Morgan, George D., 1223 Rigsby Ave., San Antonio, Tex.
Morley, Harold T., Midwest Refining Co., Box 1075, Casper, Wyo.
Morris, A. F., 212 E. Fifth St., Bartlesville, Okla.
Morse, Roy R., 402 Higgins Bldg., Los Angeles, Calif.
Morse, William C., Agricultural and Mechanical College, Miss.
Mortimore, Morris E., 408 S. State St., Lamoni, Iowa.
Moulton, Gail F., State Geol. Survey, Urbana, Ill.
Moyer, W. Irwin, 435 Sixth Ave., Pittsburgh, Pa.
Muehlberg, Max, Aarau, Switzerland
Muellerried, Frederick K. G., Apartado 8302, Mexico, D.F.

Muir, John M., Apartado 238, Tampico, Mexico
Munn, Malcolm J., Cosden Bldg., Tulsa, Okla.
Murphy, Paul C., 1719 South Detroit, Tulsa, Okla.
Myers, Desaix B., 686 LaLoma Road, Pasadena, Calif.
Myers, John C., Box 1865, Houston, Tex.
Mylius, L. A., 704 Shell Bldg., St. Louis, Mo.

Naramore, Chester, Sinclair Exploration Co., 45 Nassau St., New York City
Nash, Howard F., Apartado 285, Tampico, Mexico
Nelson, Jean O., 910 S. Michigan Ave., Chicago, Ill.
Nelson, Walter S., 1435 Bellaire St., Denver, Colo.
Nelson, Wilbur A., State Geol. Survey, University of Virginia, Charlottesville, Va.
Nesbit, Millard F., Santa Barbara, Chihuhua, Mexico
Neumann, L. Murray, Box 2045, Carter Oil Co., Tulsa, Okla.
Nevin, Charles M., Dept. of Geol., Cornell University, Ithaca, N.Y.
Newby, Jerry B., Petroleum Reclamation Co., Bradford, Pa.
Newby, Warner W., Box 1263, Ponca City, Okla.
Nichols, Charles R., 7 South "B" St., Herington, Kan.
Nickell, C. O., Box 983, Wichita Falls, Tex.
Nightingale, William T., University National Bank, Seattle, Wash.
Nisbet, John M., 703 Empire Bldg., Bartlesville, Okla.
Noble, A. H., Anglo-Saxon Petroleum Co. Ltd., St. Helen's Court, Leadenhall St., London, England
Noble, Homer A., Consolidated Oil Companies of Mexico, El Limon, S.L.P., Mexico
Noé, Adolph C., 5656 Kenwood Ave., Chicago, Ill.
Nolan, Edward D., Higgins Bldg., General Petroleum Corp., Los Angeles, Calif.
Nolan, Philip E., Venezuelan Gulf Oil Co., Maracaibo, Venezuela, S.A.
North, Lloyd, 228 W. Park Ave., San Antonio, Tex.
Norton, George H., 602 Orpheum Bldg., Wichita, Kan.
Notestein, Frank B., Whitehall Petroleum Corp., Ltd., Bamboo Villa, Shillong, Assam, India
Nowels, Kenneth B., U. S. Bureau of Mines, Laramie, Wyo.
Nowlan, Harry H., Vice-Pres. Galer Oil Co., 611–615 Clinton Bldg., Tulsa, Okla.
Nuttall, W. L. F., Longfield, Madingley Road, Cambridge, England

Officer, Herbert G., 624 W. Cherokee St., Enid, Okla.
Ogden, Laurence A., Empire Gas & Fuel Co., Oil Hill, Kan.
Ohern, D. W., 515 W. Fourteenth St., Oklahoma City, Okla.
Oldham, Albert E., Box 746, Amerada Corp., Fort Worth, Tex.
Olsson, Axel A., 48 Woodside Ave., Gloversville, N.Y.
O'Neill, Frank E., Box K, Taft, Calif.

Ordoñez, Ezequiel, Huasteca Petroleum Co., Apartado 94, Tampico, Mexico
Orr, Milo M., 415 W. Eleventh St., Oklahoma City, Okla.
Orynski, John B., Richmond Petroleum Co., Apartado 64, Bis, Mexico, D.F.
Orynski, Leonard W., Drawer 846, Colorado, Tex.
Osborne, Clarence B., 402 Security Bldg., Los Angeles, Calif.
Ott, Emil, 237 North Magdalen St., San Angelo, Tex.
Overbeck, Robert M., Caracoles Tin Company of Bolivia, Casilla 674, La Paz, Bolivia, S.A.
Owen, Edgar, 425 Elm Ave., Norman, Okla.
Owens, Allen L., Standard Oil Company of Venezuela, Apartado 85, Maracaibo, Venezuela, S. A.

Pack, Frederick J., University of Utah, Salt Lake City, Utah
Pack, R. W., Drawer 790, Beaumont, Tex.
Packard, H. J., 516 Patterson Bldg., Denver, Colo.
Page, James H., 519 E. Lincoln St., Iola, Kan.
Paige, Sidney, U. S. Geol. Survey, Washington, D. C.
Panyity, Louis S., 61 Main St., Bradford, Pa.
Parker, Everett C., 440 South Palm St., Ponca City, Okla.
Parks, Emerson M., 1029 First National Bank Bldg., Denver, Colo.
Parrish, Gaston H., Apartado 241, Tampico, Mexico
Parsons, C. W., 200 Bush St., Marland Oil Co., San Francisco, Calif.
Patrick, Walden W., Indian Territory Illum. Co., Bartlesville, Okla.
Patterson, Joseph M., Box 842, Carlsbad, New Mexico
Patton, Horace B., 3111 W. Thirty-sixth Ave., Denver, Colo.
Patton, Leroy T., Texas Technological College, Lubbock, Tex.
Paxson, Roland B., 3204 Smith St., Houston, Tex.
Peabody, Harlan W., Box 625, Stillwater, Okla.
Pellekaan, W. van Holst, Roxana Petroleum Corp., Dallas Athletic Club Bldg., Dallas, Tex.
Pellissier, Andre, Pechelbronn, Merkwiller, Bas-Rhin, Strasbourg, France
Pemberton, J. R., 525 N. Palm Drive, Beverly Hills, Calif.
Penny, Frederick W., Unirea Societate de Petrol, Casuta Postala No. 1, Ploesti, Roumania
Pepperberg, Leon J., American Exchange National Bank Bldg., Dallas, Tex.
Perini, Vincent C., Jr., Box 581, Cisco, Tex.
Perkins, Joseph M., Box 957, Eastland, Tex.
Perrine, Irving, 704 Braniff Bldg., Oklahoma City, Okla.
Peterson, Clarence J., 413 First National Bank Bldg., Denver, Colo.
Petsch, Arthur H., Apartado 10, Frontera, Tabasco, Mexico
Petty, Dabney E., 10 Tenth St., San Antonio, Tex.
Phelps, Robert W., 424 S. Madrona Ave., Brea, Calif.
Pishel, Max A., 1210 South Cheyenne, Tulsa, Okla.
Plata, Belisario, Apartado 224, Bogota, Colombia, S.A.

Plummer, F. B., 504 Colquitt St., Houston, Tex.
Pogue, Joseph E., 42 W. Twelfth St., New York, N.Y.
Porch, Edwin L., Jr., F. Julius Fohs, 51 E. Forty-second St., New York City
Potter, G. C., Box 2190, Tulsa, Okla.
Poulsen, Frank E., Box 657, Mexia, Tex.
Powers, Sidney, Box 2022, Amerada Corp., Tulsa, Okla.
Pratt, Wallace E., 911 Humble Bldg., Houston, Tex.
Preece, Rae, 404 Atlas Life Bldg., Tulsa, Okla.
Prettyman, Thomas M., Drawer 500, Cisco, Tex.
Price, Sylvan S., 704 Mid-Continent Bldg., Tulsa, Okla.
Price, W. Armstrong, 129 W. Alabama Ave., Houston, Tex.
Pritchard, George B., 6 Kooyongkoot Road, Hawthorn, Melbourne, Victoria, Australia
Prommel, Harald W. C., Perkins & Cullum, 1210 City National Bank Bldg., Wichita Falls, Tex.
Prout, F. S., 413 First National Bank Bldg., Denver, Colo.
Purdy, C. Wesley, 65 Stonehedge Road, Andover, Mass.
Pyle, James R., Box 416, Owensboro, Ky.

Radcliffe, Donald H., 410–11 Mid-Continent Bldg., Tulsa, Okla.
Rade, Henry S., 70 Morningside Drive, New York City
Radler, Dollie, Box 2022, Amerada Corp., Tulsa, Okla.
Rae, Colin C., 886 South Gilpin St., Denver, Colo.
Randolph, E. Oscar, Black Mountain, N.C.
Rath, Charles M., Box 240, Denver, Colo.
Rau, Harold L., Box 2045, Tulsa, Okla.
Ravicz, Louis, Hayden, Stone & Co., 25 Broad St., New York City
Read, M. K., 211 Commercial National Bank Bldg., Muskogee, Okla.
Reed, Ralph D., 1021 Forest Court, Palo Alto, Calif.
Reeds, A. C., Box 635, San Angelo, Tex.
Rees, Forest R., McBrayer Bldg, Okmulgee, Okla.
Reeves, Frank W., 1112 Kirby Bldg., Dallas, Tex.
Reeves, John R., Empire Co., Geol. Dept., Oil Hill, Kan.
Reger, David B., Box 816, Morgantown, W.Va.
Reisher, Paul H., Box 2044, Tulsa, Okla.
Remington, Arthur E., 304 Paddock St., Watertown, N.Y.
Renaud, Charles L., Drawer 500, Cisco, Tex.
Renick, B. Coleman, U. S. Geol. Survey, Washington, D.C.
Rennie, Waldo E., 1725 Williams St., Denver, Colo.
Rettger, Robert E., Sun Oil Co., Box 1109, Dallas, Tex.
Reynolds, Roy A., Box 1001, Fort Worth, Tex.
Reynolds, W. J., The Royal Societies Club, 63 St. James St., London, S.W. 1, England
Rhine, Elton, Box 545, Shreveport, La.

Rhoades, Ralph O., Box 804, El Dorado, Ark.
Rhoades, Roy S., 1222 First National Bank Bldg., Denver, Colo.
Rich, John L., Box 3, Ottawa, Kan.
Richards, J. T., Box 175, Ponca City, Okla.
Richards, Ralph, 2717 Connecticut Ave., N.W., Washington, D.C.
Richards, Raymond, Tide Water Oil Co., 11 Broadway, New York, N.Y.
Richardson, G. B., U. S. Geol. Survey, Washington, D.C.
Riddle, Donald D., Claridon Road, Chardon, Ohio
Rider, Charles R., Apartado 223, Maracaibo, Venezuela, S.A.
Riggs, Robert J., 419 N. Tacoma, Tulsa, Okla.
Ring, Dewitt T., Box 804, El Dorado, Ark.
Roark, Edward L., 400 S. Palm St., Ponca City, Okla.
Roark, Louis, 926 N. Collins St., Okmulgee, Okla.
Roark, Ralph B., 400 S. Palm St., Ponca City, Okla.
Roberts, John R., U. S. Subtreasury Bldg., % Internal Revenue Agent, San Francisco, Calif.
Roberts, Morgan E., Pure Oil Co., Geol. Dept., Mexia, Tex.
Robinson, Ernest G., 527½ E. Laurel St., San Antonio, Tex.
Robinson, Heath M., 304 American Exchange Bank Bldg., Dallas, Tex.
Robinson, J. French, 545 William Penn Way, Pittsburgh, Pa.
Robinson, Dr. Wilber I., Michigan Geol. Survey, Lansing, Mich.
Rogers, Ola J., Cleveland, Okla.
Rogers, Reese F., Oil and Gas Section, Engineering Div., Treasury Annex No. 2, Washington, D.C.
Rohwer, F. W., Apartado 33, Maracaibo, Venezuela, S.A.
Rollin, George S., 1729 S. Cincinnati Ave., Tulsa, Okla.
Romine, Thomas B., address unknown
Ross, Clarence S., U. S. Geol. Survey, Washington, D.C.
Ross, J. C., Reiter-Foster Oil Corp., Atlas Life Bldg., Tulsa, Okla.
Ross, John S., Box 428, Midwest, Wyo.
Rothrock, E. Paul, 312 Lewis St., Vermilion, S.D.
Rothrock, Howard E., Box 1911, 508 New Wright Bldg., Tulsa, Okla.
Roundy, P. V., U. S. Geol. Survey, Washington, D.C.
Row, Charles H., The Sun Oil Co., 601 Travis Bldg., San Antonio, Tex.
Rowley, Alden B., 1559 S. Yorktown, Tulsa, Okla.
Rubey, William W., U. S. Geol. Survey, Washington, D.C.
Ruby, Glen M., 935 Saint Paul St., Denver, Colo.
Ruedemann, Paul, 505 Atlas Bldg., Tulsa, Okla.
Russ, Leon F., 206 Magnolia Bldg., Dallas, Tex.
Russell, Philip G., Box 1067, Duncan, Okla.
Russell, William L., 430 Temple St., New Haven, Conn.
Russom, Vaughn W., 709 Empire Masonic Bldg., Bartlesville, Okla.
Sale, Clarence M., 780 Pickard, Norman, Okla.

Sammons, George B., 56 Church St., Toronto, Canada
Sands, J. M., Phillips Petroleum Co., Bartlesville, Okla.
Sawtelle, George, 1815 Holman Ave., Houston, Tex.
Sawyer, Roger, 627 W. Fourteenth St., Okmulgee, Okla.
Schieferdecker, A. A. G., Caribbean Petroleum Co., Maracaibo, Venezuela, S.A.
Schilling, Karl H., 1005 E. Main St., Okmulgee, Okla.
Schneider, Henry G., Dixie Oil Co., Shreveport, La.
Scholl, Louis A., Jr., 498 Orchard St., Oakland, Calif.
Schoolfield, R. F., 916 Salinas Ave., Laredo, Tex.
Schramm, E. Frank, Station A, Box 1258, Lincoln, Neb.
Schroyer, C. R., Worthington, Ohio.
Schuchert, Dr. Charles, Yale University, New Haven, Conn.
Schumacher, Jan P., First National Bank, Houston, Tex.
Schwarzenbek, Francis X., U. S. Bureau of Mines, Winnett, Mont.
Schwennesen, Alvin T., 543 First National Bank Bldg., Houston, Tex.
Scott, Gayle, Texas Christian University, Fort Worth, Tex.
Scott, H. M., 902 Petroleum Bldg., Tulsa, Okla.
Scott, Walter W., Pure Oil Co., Box 2007, Tulsa, Okla.
Scudder, Ernest W., Box 1144, Wichita, Kans.
Sealey, Fred C., Drawer F, The Texas Co., Houston, Tex.
Sears, Julian D., 209 E. Underwood St., Chevy Chase, Md.
Segall, Julius, 602 Great Republic Life Bldg., Los Angeles, Calif.
Selig, A. L., 843 Dudley Drive, Shreveport, La.
Sellards, E. H., 505 W. Thirty-third St., Austin, Tex.
Semmes, Douglas R., 1316 Porter St., Richmond, Va.
Severy, C. L., 714 Kennedy Bldg., Tulsa, Okla.
Shannon, Charles W., 517 Flood St., Norman, Okla.
Shaw, Eugene W., 11 Taylor St., Chevy Chase, Md.
Shaw, Everett S., address unknown
Shayes, Fred P., Box 788, Beeville, Tex.
Shea, Edward F., 1545 N. Main St., Tulsa, Okla.
Shearer, Harold K., Standard Oil Company of Louisiana, Box 1094, Shreveport, La.
Sheldon, Israel R., 700 Denver St., Wichita Falls, Tex.
Sheldon, William W., 614 S. Elwood Ave., Tulsa, Okla.
Shepard, Edward M., 1403 Benton Ave., Springfield, Mo.
Sherwood, T. C., Jr., 527 E. Twelfth St., Bartlesville, Okla.
Shiarella, Nicholas W., 731 Fifth Ave., New Kensington, Pa.
Shidel, Harold R., Box 865, Wichita, Kan.
Shuler, Ellis W., Southern Methodist University, Dallas, Tex.
Shutt, Roscoe E., Dallas Athletic Club Bldg., Roxana Petroleum Corp., Dallas, Tex.

Sickler, Jack M., Union Oil Co., Los Angeles, Calif.
Siemon, Fred, Bakersfield Club, Bakersfield, Calif.
Simonds, Frederic W., University of Texas, Austin, Tex.
Sinclair, E. G., 421 Devine St., Casper, Wyo.
Singewald, Joseph T., Jr., 17 W. Twenty-ninth St., Baltimore, Md.
Slipper, S. E., 215 Sixth Avenue West, Calgary, Alta, Canada
Small, Walter M., Apartado 76, Tampico, Mexico
Smith, Carl D., 636 Kennedy Bldg., Tulsa, Okla.
Smith, E. Eggleston, Room 5849 A, Grand Central Terminal, New York City
Smith, Frank M., 3933 Revere Ave., Los Angeles, Calif.
Smith, George O., U. S. Coal Commission, Interior Bldg., Washington, D.C.
Smith, Lloyd B., 2617 Dillard St., Shreveport, La.
Smith, Richard A., Geol. Survey Div., State Office Bldg., Lansing, Mich.
Snider, George W., Box 2045, Tulsa, Okla.
Snider, L. B., Box 2022, Amerada Corp., Tulsa, Okla.
Snider, L. C., H. L. Doherty & Co., 60 Wall St., New York, N.Y.
Snively, H. Norman, 720 W. Spruce St., Rawlins, Wyo.
Snow, Dale R., 1325 S. Owasso St., Tulsa, Okla.
Snyder, John Y., 1211 Merchants Bldg., Sherveport, La.
Somers, Ransom E., Oil and Gas Bldg., University of Pittsburgh, Pittsburgh, Pa.
Soper, Edgar K., 2806 Park Ave., Minneapolis, Minn.
Souther, John B., 916 Salinas St., Laredo, Tex.
Soyster, Hale B., U. S. Bureau of Mines, Whiteagle, Okla.
Spieker, Edmund M., Ohio State University, Dept. of Geol., Columbus, Ohio
Spofford, Howard N., Box 1836, El Dorado, Ark.
Spooner, W. C., Arkansas Natural Gas Co., Box 1195, Shreveport, La.
Springfield, Carl K., Box 1116, Austin, Tex.
Stacy, Dean M., 704 Braniff Bldg., Oklahoma City, Okla.
Stalder, Walter, 925 Crocker Bldg., San Francisco, Calif.
Stander, Arthur E., Box 912, Tulsa, Okla.
Starke, Eric A., 412 Security Bldg., Los Angeles, Calif.
Stathers, Silas C., Standard Oil Company of Louisiana, Box 1094, Shreveport, La.
Stauffer, Clinton R., 1120 Fifth St., S.E., Minneapolis, Minn.
St. Clair, Stuart, 25 Broadway, New York City
Stebinger, Eugene, Room 719, Edificio Banca Boston, Buenos Aires, Argentina, S.A.
Steinmayer, R. A., Tulane University, New Orleans, La.
Steiny, Homer J., 480 Associated Oil Bldg., San Francisco, Calif.
Stephenson, Cuthbert D., Box 923, Pawhuska, Okla.
Stephenson, Eugene A., % Ralph E. Davis, 1710 Union Bank Bldg., Pittsburgh, Pa.

Stephenson, Lloyd W., 3421 Lowell St., Washington, D.C.
Sterrett, Douglas B., 616 Palace Bldg., Tulsa, Okla.
Steubing, W. C., 513 National Bank of Commerce Bldg., San Antonio, Tex.
Stevens, George R., 324 Washington Ave., Shreveport, La.
Stevens, John B., Associated Oil Co., Fellows, Calif.
Stewart, Hugh A., 1415 Milwaukee St., Denver, Colo.
Stewart, Irvine E., 926 Patterson Bldg., Denver, Colo.
Stewart, James S., Negritos, Talara, Peru, S.A.
Stiles, Edmund B., Pure Oil Co., Box 657, Mexia, Tex.
Stoner, R. C., 225 Bush St., Production Dept., Standard Oil Co., San Francisco, Calif.
Storm, Lynn W., The Sun Co., Box 1109, Dallas, Tex.
Storm, William W., 1806 Buchanan St., Wichita Falls, Tex.
Straub, Charles E., 515 W–K–H Bldg., % Dixie Oil Co. Inc., Wichita, Kan.
Stroud, Ben K., Box 510 Arcade Station, Los Angeles, Calif.
Stryker, William L., Fredonia, Kan.
Studt, Charles W., Southwestern Gas Co., Commercial National Bank Bldg., Independence, Kan.
Stutzer, Dr. Otto, Apartado 437, Bogota, Columbia, S.A.
Suman, George O., Jr., Associated Oil Co., Oil Center, Calif.
Suman, John R., 316 Southern Pacific Bldg., Houston, Tex.
Sutton, Frederick A., Room 719, Edificio Banco Boston, Buenos Aires, Argentine, S.A.
Swarts, Clifton R., 415 Citizens National Bank Bldg., Los Angeles, Calif.
Swigart, T. E., The Shell Co., Higgins Bldg., Los Angeles, Calif.

Taff, Joseph A., 79 New Montgomery St., San Francisco, Calif.
Takahashi, Raphael Jun-ichi, Institute of Petrology, Imperial University, Sendai, Japan
Taliaferro, Nicholas L., Bacon Hall, University of California, Berkeley, Calif.
Tansey, V. O., 2826 E. Seventy-sixth Place, Chicago, Ill.
Tarr, Russell S., Box 1958, Tulsa, Okla.
Tatum, James L., Box 31, Laredo, Tex.
Taylor, Charles H., 701 Braniff Bldg., Oklahoma City, Okla.
Teas, L. P., Humble Refining Co., Box 198, Shreveport, La.
Templeton, James B., 515 N. Seventeenth St., Muskogee, Okla.
Tester, Allen C., Dept. of Geol., University of Iowa, Iowa City, Iowa
Thayer, Warren N., 527 Security Bldg., Los Angeles, Calif.
Thom, William T., Jr., U. S. Geol. Survey, Washington, D.C.
Thomas, C. R., Box 2022, Tulsa, Okla.
Thomas, Elmslie T., Collins, Ohio
Thomas, J. Elmer, 602 Fort Worth Club Bldg., Fort Worth, Tex.
Thompson, A. Beeby, 18 St. Swithins Lane, London E.C. 4, England

Thompson, James D., Jr., Box 737, Fort Worth, Tex.
Thompson, Robert R., Box 297, Thurber, Tex.
Thompson, Sheridan A., 214 Gulf Bldg., Houston, Tex.
Thompson, Wallace C., Box 1517, Wichita Falls, Tex.
Thomson, H. Britton, 5312 La Cresta Court, Los Angeles, Calif.
Thoms, Clifford C., State Mining Bureau, Santa Paula, Calif.
Thornburg, Dwight H., Roxana Petroleum Corp., Athletic Club Bldg., Dallas, Tex.
Thralls, Warren H., 426 N. Topeka St., Wichita, Kan.
Tickell, Frederick G., 652 Forest Ave., Palo Alto, Calif.
Tieje, Arthur J., 2906 S. Hobart Blvd., Los Angeles, Calif.
Toepelman, Walter C., Dept. of Geol., University of Colorado, Boulder, Colo.
Tomlinson, Charles W., 610 Simpson Bldg., Ardmore, Okla.
Tong, James A., Apartado 234, Maracaibo, Venezuela, S.A.
Tough, Frederick B., Bureau of Mines, Washington, D.C.
Trager, Earl A., Marland Refining Co., Ponca City, Okla.
Trout, L. E. 419–21 Perkins Snider Bldg., Wichita Falls, Tex.
Trowbridge, Arthur C., 1182 E. Court St., Iowa City, Iowa
Troxell, John N., Box 912, Tulsa, Okla.
Truex, Arthur F., 1815 Easton Place, Tulsa, Okla.
Trumbull, Loyal W., 1835 Gaylord St., Denver, Colo.
Trumpy, Dr. Daniel, C.M.P. Aguila, Apartado 86, Puerto Mexico, Ver, Mexico
Tucker, Rietz C., Box 265, Morgantown, W.Va.
Turman, Arthur F., 1128 Standard Oil Bldg., San Francisco, Calif.
Twenhofel, W. H., Science Hall, University of Wisconsin, Madison, Wis.

Udden, Johan A., Bureau of Economic Geology, University Station, Austin, Tex.
Udden, Jon A., 1140 S. Owasso St., Tulsa, Okla.
Umpleby, Joseph B., 710 Chautauqua Ave., Norman, Okla.

Valerius, M. M., 102 Wilcox Bldg., Tulsa, Okla.
van Aubel, Henry E., The Caribbean Petroleum Co., Maracaibo, Venezuela, S.A.
Van Burgh, Lisle R., 1095 Jackson St., Denver, Colo.
Van Couvering, Martin, Suite 841, Securities Bldg., Los Angeles, Calif.
van der Gracht, W. A. J. M. van Waterschoot, Marland Refining Co., Ponca City, Okla.
Vander Leck, Lawrence, Box 117, Altadena, Calif.
van der Linden, Bernard H., % Administrator B. P. M. Pankalan Brandan, North Sumatra, D.E.I.
van Diermen, J. F., Balikpapan, Borneo, D.E.I.
Vandiver, Vincent W., Foreign Production Dept., Standard Oil Company of New Jersey, Room 376, 26 Broadway, New York City

Van Gilder, H. R., Graduate Men's Club, 124 Wall St., New Haven, Conn.
Van Gogh, F. A. A., Bataafsche Petr. Mpy., 30 Carel van Bylandtlaan, The Hague, Holland
Van Tuyl, Francis M., Colorado School of Mines, Golden, Colo.
Vaughan, F. E., 1358 N. La Brea Ave., Los Angeles, Calif.
Vaughn, T. Wayland, Scripps Institute of Oceanography, La Jolla, Calif.
Veatch, A. C., 5 Central Drive, Port Washington, Long Island, N.Y.
Vernon, I. James, Coweta, Okla.
Ver Weibe, Walter A., 1025 Packard St., Ann Arbor, Mich.
Vetter, J. M., Rio Bravo Oil Co., Houston, Tex.
Vickery, Frederick P., 521 Spencer St., Glendale, Calif.
Villa, Mario L., Centro Naval Florida 801, Buenos Aires, Argentina, S.A.
Vorck, Charles R., 506 Fifteenth St., Golden, Colo.
Vrang, Christion, 503 Scott Bldg., Salt Lake City, Utah

Wade, Bruce, Trenton, Tenn.
Wagener, Charles H., Box 121, San Antonio, Tex.
Wagner, Carroll M., 1003 Higgins Bldg., Los Angeles, Calif.
Wagy, Earl W., 225 Bush St., Standard Oil Bldg., San Francisco, Calif.
Waite, V. V., 906 Insurance Bldg., Dallas, Tex.
Walker, Lucian H., 504 Exchange Bank Bldg., Tulsa, Okla.
Walker, W. L., 1400 Delaware Ave., Bartlesville, Okla.
Walters, Ray P., Romano Americano, 126 Calea Victoriei, Bucharest, Roumania
Ward, Dr. Freeman, 323 Lewis St., Vermilion, S.D.
Ware, Thomas T., Wade Hotel, Duncan, Okla.
Waring, Gerald A., Margay Oil Corp., Box 2103, Tulsa, Okla.
Wark, Thomas L., 79 New Montgomery St., Room 477, San Francisco, Calif.
Warner, Charles A., 420 Commerce Bldg., Okmulgee, Okla.
Warner, Julius H., 1016 First National Bank Bldg., Denver, Colo.
Warren, Van Court, 1101 Los Angeles Stock Exchange Bldg., Los Angeles, Calif.
Washburne, Chester W., 2 Rector St., New York City
Wasson, Theron, Geol. Dept., Pure Oil Co., Columbus, Ohio
Weaver, Paul, Apartado 150, Tampico, Mexico
Weeks, Lewis G., Room 322, 26 Broadway, New York, N.Y.
Wegemann, Carroll H., Pan-American Exploration Co., 120 Broadway, New York City
Weidman, Samuel, 814 Monnett St., Norman, Okla.
Weirich, T. E., Geol. Dept., Skelly Oil Co., Tulsa, Okla.
Welker, George E., 420 W. Third St., Oil City, Pa.
Wellings, Frank E., Apartado 4, Matamoros, Tamps., Mexico
Wells, Lloyd E., Box 446, Snyder, Tex.
Wells, Samuel W., 507 Petroleum Bldg., Okmulgee, Okla.

Welsh, Leroy G., 617 Exchange National Bank Bldg., Tulsa, Okla.
Westby, Gerald, 1549 Saint Paul St., Denver, Colo.
Whisenant, J. B., Richmond Petroleum Co., Apartado 33, Maracaibo, Venezuela, S.A.
White, David, U. S. Geol. Survey, Washington, D.C.
White, Edwin E., Box 595, Paintsville, Ky.
White, I. C., state geologist, Morgantown, W.Va.
White, Kessack D., 7 piso, Avenida Roque Saenz Peña 567, Buenos Aires, Argentina, S.A.
White, L. Ansel, Pratt, Kan.
White, Luther H., 211 E. Jasper St., Tulsa, Okla.
White, Roger F., 818 Hellman Bank Bldg., Los Angeles, Calif.
Whitehead, R. Brooks, 702 Magnolia Bldg., Dallas, Tex.
Whitney, F. L., University of Texas, Austin, Tex.
Whitney, Paul B., Taranaki Oil Co., Plymouth, New Zealand
Whittier, William H., Roxana Petroleum Corp., Athletic Club Bldg., Dallas, Tex.
Whitwell, E. V., 2288 Ivy St., Denver, Colo.
Whyman, Lawrence O., 510 E. Courtland Place, San Antonio, Tex.
Williams, A. J., 538 Lahoma Ave., Norman, Okla.
Williams, D. W., 3118 Newton St. N.E., Washington, D.C.
Williams, Herbert E., 307 Kennedy Bldg., Tulsa, Okla.
Williams, W. A., White Oil Corp., Bing Bldg., Houston, Tex.
Willis, Cornelius G., Marland Oil Co., Ponca City, Okla.
Willis, S. Morse, Wewoka, Okla.
Williston, Samuel H., Apartado 34, Maracaibo, Venezuela, S.A.
Wilson, Edward B., Humphreys Corp., Mason Bldg., Houston, Tex.
Wilson, Malcolm E., 928 Monrovia St., Shreveport, La.
Wilson, Roy A., Faculty Exchange, University of Oklahoma, Norman, Okla.
Wilson, Walter B., Box 2044, Tulsa, Okla.
Winchester, Dean E., 230 Steel Bldg., Denver, Colo.
Winsor Owen A., Black Gold Producing Co., Tulsa, Okla.
Winter, Niles B., 2611 Dillard St., Shreveport, La.
Winton, Will M., Texas Christian University, Fort Worth, Tex.
Witt, Herbert N., 512 Sharon Bldg., San Francisco, Calif.
Witteveen, G., Caribbean Petroleum Co., Maracaibo, Venezuela, S.A.
Wohlford, Charles J., Box 1817, Houston, Tex.
Wolff, Deane J., 1632 Eleventh St., Wichita Falls, Tex.
Wood, Robert H., 302 Security Nat'l. Bank Bldg., Tulsa, Okla.
Wood, Virgil O., 302 Security Nat'l Bank Bldg., Tulsa, Okla
Woodford, Alfred O., Claremont, California, Pomona College
Woodruff, E. G., 1611 S. Detroit St., Tulsa, Okla.
Woods, Sam H., Box 296, Ardmore, Okla.

Woodward, Harold R., Box 831, Eldorado, Kan.
Woolsey, E. V., Atlantic Oil Prod. Co., Dallas, Tex.
Wrather, William E., 6044 Bryan Parkway, Dallas, Tex.
Wright, Arthur P., 904 Petroleum Bldg., Tulsa, Okla.
Wright, Frederick S. 1660 Ogden St., Denver, Colo.
Wright, Harry F., Nowata Oil & Refining Co. Bldg., 206 South Cheyenne, Tulsa, Okla.
Wright, William J., % A. B. Marshall, Bear River, Digby County, Nova Scotia

Yager, Charles E., Jr., 1014 Braniff Bldg., Oklahoma City, Okla.
Yoakam, Coler A., Box 276, Holdenville, Okla.
Young, E. J., 1128 Standard Oil Bldg., San Francisco, Calif.
Youngs, L. J., 122 N. Mulberry St., Eureka, Kan.
Younkman, Harry, 122 N. Lawton St., Tulsa, Okla.

Zimmerman, James Z., Delmont, Westmoreland County, Pa.
Zoller, Lawrence J., 406 Exchange National Bank Bldg., Tulsa, Okla.

ASSOCIATE MEMBERS

Absher, Kenneth B., 805 W. Russell Place, San Antonio, Tex.
Ackers, A. L., Drawer 846, Colorado, Tex.
Adams, James V., Humble Oil & Refining Co., Wichita Falls, Tex.
Aguerrevere, Pedro I., Attention Mrs. C. D. Wetmore, Librarian, Henry Doherty & Co., 60 Wall St., New York City
Aguerrevere, S. E., % V. R. Garfias, Mgr., Foreign Dept., Henry L. Doherty & Co., 60 Wall St., New York City
Ainsworth, David, 259 N. Clifton Ave., Wichita, Kan.
Aldrich, G. Frank, Box 72, Wagoner, Okla.
Allan, Thomas H., Box 362, Russell, Kan.
Allen, Donald M., Vian, Okla.
Allison, A. P., address unknown
Anderson, Ray B., 2716 Frankfort Ave., Louisville, Ky.
Andrews, George L., Standard Oil Co., Production Dept., Whittier, Calif.
Andrews, Philip, Apartado 33, Maracaibo, Venezuela, S.A.
Arnold, James E., Twin State Oil Co., Box 1501, Tulsa, Okla.
Atkinson, Wm. H., 917 Braniff Bldg., Oklahoma City, Okla.
Austin, Philip H., East Ave., Greenville, Pa.

Bace, A. C., 314 Humble Bldg., Houston, Tex.
Baden, M. W., Box 520, Winfield, Kan.
Bale, Hubert, Geol. Dept., Marland Refining Co., Ponca City, Okla.
Ballard, Andrew L., 703 Travis Bldg., San Antonio, Tex.

Ballard, James L., Apartment 4D, 400 Riverside Drive, New York City
Banks, Paul W., General Petroleum Corp., Maricopa, Calif.
Barcklow, John C., Box 2045, Tulsa, Okla.
Barth, William A., Louisiana Oil Refining Corp., First National Bank Bldg., Shreveport, La.
Barwick, John S., Empire Gas & Fuel Co., Eldorado, Kan.
Bayer, Horace M., Box 368, San Angelo, Tex.
Belford, Leland S., Box 71, Eldorado, Kan.
Bell, Olin G., Humble Oil & Refining Co., Kingsville, Tex.
Benson, Dale L., 713 Masonic Bldg., Bartlesville, Okla.
Bentz, Ivan V., Box 153, Bartlesville, Okla.
Berwald, W. B., 308 Congress St., Bradford, Pa.
Bingham, Dwight H., 531 Clarence St., Lake Charles, La.
Blackburn, William D., 1012 McGregor St., Houston, Tex.
Blanchard, J. B., Box 564, San Antonio, Tex.
Blanpied, B. W., Box 358, Tupelo, Miss.
Block, Clarence I., Box 31, Sterling City, Tex.
Blodget, Ward B., 302 Kerckhoff Bldg., Los Angeles, Calif.
Bond, Marshall, 328 E. Islay St., Santa Barbara, Calif.
Bowen, Lot, 465 Belmont Ave., Los Angeles, Calif.
Boyle, George R., 417 Travis Bldg., San Antonio, Tex.
Bradley, Everett L., 1007 Tennessee St., Lawrence, Kan.
Bramlette, M. N., Casilla 1331, Guyaquil, Ecuador, S.A.
Brant, Ralph Allen, Shaffer Oil & Ref. Co., 729 Kennedy Bldg., Tulsa, Okla.
Braugh, Donald D., address unknown
Bright, Richard T., 1329 S. Boston, Tulsa, Okla.
Briscoe, Glenn O., 504 Central National Bank Bldg., San Angelo, Tex.
Brittain, Reuben E., Jr., 231 E. Twelfth St., Oklahoma City, Okla.
Brockway, E. R., 704 S. Sixth St., Marshall, Ill.
Brown, J. Marshall, Box 737, Gulf Prod. Co., Fort Worth, Tex.
Brown, Richard I., Standard Oil Co., Producing Dept., Taft, Calif.
Bruce, George H., 306 Bitting Bldg., Wichita, Kan.
Brucks, Ernest W., Apartado 657, Transcontinental Oil Co., Tampico, Mex.
Buchanan, George S., Carter Oil Co., Box 2045, Tulsa, Okla.
Burchfiel, Hugh L., Drawer 846, The California Co., Colorado, Tex.
Burley, John E., 112 E. Eleventh St., Oklahoma City, Okla.
Burress, Wm. Arthur, Box 57, Okmulgee, Okla.
Butcher, Cary P., Box 311, San Angelo, Tex.
Buzzo, Thomas W., Box 304, San Angelo, Tex.
Byram, Ronald W., Box 1618, University Station, Austin, Tex.

Cadle, Austin, Room 1523, Standard Oil Bldg., San Francisco, Calif.
Calvert, Charles L., 1321 W. Warner St., Guthrie, Okla.

Cannon, Robert L., 4312 Avenue F, Austin, Tex.
Carlson, Edwin N., Box 1116, 917 First National Bank Bldg., Wichita, Kan.
Carpenter, Marble J., 709 Masonic Bldg., Bartlesville, Okla.
Carsey, J. Ben, Box 537, San Angelo, Tex.
Carter, Frank B., Box 63, R.D. 2, Norwalk, Calif.
Cartwright, Lon D., Jr., Leland Stanford University, Palo Alto, Calif.
Case, Leslie C., Box 2044, Geol. Dept., Tulsa, Okla.
Cash, Thornton C., Box 612, Humble Oil Co., Corsicana, Tex.
Charles, Homer H., 169 N. Main St., Warsaw, N.Y.
Chatburn, George R., Jr., Hoffer Oil Corp., 611–12 Petroleum Bldg., Tulsa, Okla.
Christie, Robert S., Fairview Road, Crum Lynn, Pa.
Clark, H. Smith, 536 Third Ave., Upland, Calif.
Clawson, William W., Apartado 172, Maracaibo, Venezuela, S.A.
Clay, J. Withers, 304 Ward Bldg., Shreveport, La.
Clifton, R. L., 564 N. Tenth St., Enid, Okla.
Cochran, Phil K., Standard Oil Co., Apartado 85, Maracaibo, Venezuela, S.A.
Cole, Edwin G., Sinclair Oil & Gas Co., Enid, Okla.
Cole, Virgil B., Apartado 154, Cartagena, Colombia, S.A.
Coleman, Tom L., Box 51, Wewoka, Okla.
Collins, C. Philip, Trinidad Lake Petroleum Ltd., Brighton, Trinidad, B.W.I.
Collins, Wallace H., 2401 Thirty-seventh St. N.W., Washington, D.C.
Conkling, Russell C., Box 620, Roxana Petroleum Corp., San Angelo, Tex.
Conkling, Wm. Henry, 220 Bird St., San Angelo, Tex.
Cook, Carroll E., 506 W. Twenty-second St., Austin, Tex.
Cooper, Chalmer L., Okla. Geol. Survey, Norman, Okla.
Corby, Grant W., Room 1015, 200 Bush St., San Francisco, Calif.
Cottingham, Virgil E., 826 E. Seventh St., Ada, Okla.
Crandall, Kenneth H., The California Co., 419 Securities Bldg., Billings, Mont.
Crandall, Richard R., Bin "R," Calif. Petr. Corp., Long Beach, Calif.
Cullen, Ronald J., Box 2022, Tulsa, Okla.

Dakin, Francis W., 1108 Colcord Bldg., Oklahoma City, Okla.
Daniels, Harold G., White Eagle Oil & Refining Co., F. &. M Bank Bldg., Fort Worth, Tex.
Daniels, James I., Marland Oil Co., Ponca City, Okla.
Dannettell, Merle Q., 4923 W. Thirty-first Ave., Denver, Colo.
Daubert, Charles A., 1606 Twelfth St., Wichita Falls, Tex.
Dawson, Wm. A., Stillwater, Okla.
Deegan, Charles J., Dept. of Economics, Marland Refining Co., Ponca City, Okla.
DeFord, Ronald K., Box 660, Abilene, Tex.
Disney, Orville A., 400 First National Bank Bldg., Wichita Falls, Tex.

Diven, Quay S., 1067 Gladys Ave., Long Beach, Calif.
Doane, George H., 2033 West Seventh St., Los Angeles, Calif.
Dodd, Harold V., 482 N. Oxford Ave., Los Angeles, Calif.
Dolphin, Adrian J., Box 154, Owensboro, Ky.
Donahue, Frank, 402 S. Fourth St., Ponca City, Okla.
Doolittle, Jefferson J., 2525 Wilshire Bldg., Los Angeles, Calif.
Dorr, James B., Apartado 94, Huasteca Petr. Co., Tampico, Mexico
Doyle, John J., Box 198, Humble Oil & Refining Co., Shreveport, La.
Dugan, Ira E., 301 S. Lake St., Ponca City, Okla.
Dunn, George V., 232 Newport St., Long Beach, Calif.

Eagles, Homer M., Room 1060, 26 Broadway, New York City
Earl, Will F., Transcontinental Oil Co., Tulsa, Okla.
Emch, John W., Box 1520, Fort Worth, Tex.
Engleman, Rolf, Apartado 255, Tampico, Mexico
Erwin, Andrew V., 515 Mayo Bldg., Tulsa, Okla.
Evans, Louis H., 415 Citizens National Bank Bldg., Los Angeles, Calif.
FitzGerald, James, Jr., 709 Empire Masonic Bldg., Bartlesville, Okla.
Fortier, Leo R., Box 1263, Ponca City, Okla.
Foster, Alden W., Schenley Hotel, Pittsburgh, Pa.
Fralich, Charles E., 1006 Tenth St., Wichita Falls, Tex.
Frost, Jack, 304 American Exchange National Bank Bldg., Dallas, Tex.
Funk, Marion H., Box 1131, Station A, Lincoln, Neb.

Gaddess, Jack, 706 E. Second St., Oil City, Pa.
Gahring, William R., 844 Lahoma Ave., Norman, Okla.
Gallagher, Wm. G., Jr., Box 571, Fort Collins, Colo.
Galloway, John O., 525 Mapleton Ave., Boulder, Colo.
Gardescu, Ionel I., Romano-Americana, Ploesti, Roumania
Gardiner, Chester M., 931 Security Bldg., Los Angeles, Calif.
Getzendaner, A. E., % F. M. Getzendaner, Uvalde, Tex.
Gish, Wesley G., Box 2026, Sinclair Oil Co., Tulsa, Okla.
Godde, Harry A., 6000 Franklin Ave., Hollywood, Calif.
Goodrich, Raymond H., 908 Humble Bldg., Houston, Tex.
Gould, James N., Box 1817, Houston, Tex.
Graham, Almon J., 507 White Bldg., Buffalo, N.Y.
Grant, Paul A., Columbus, Mont.
Green, Guy E., Mason, Tex.
Greene, Ray G., 43 Ryland Bldg., San Jose, Calif.
Griffith, Cunningham L., La Espuela Oil Co., Apartado 1390, Tampico, Mexico
Grigsby, Rhydon B., Box 1092, Wichita Falls, Tex.
Grinsfelder, Sam, 112 S. Grant St., Fort Collins, Colo.
Grogan, Samuel A., Apartado 106, Tampico, Mexico

Gross, P. S., 122 W. Fifth St., Kansas City, Mo.
Grumbine, Grant B., 627 E. Fifteenth St., Oklahoma City, Okla.
Gunby, Merle F., % Hugh T. Jones, Chanute, Kan.

Haecker, Frederick W., Box 1322, Globe, Ariz.
Hagy, Lawrence R., 315 W. Nineteenth St., Oklahoma City, Okla.
Hahn, Raymond R., Barnes, Warren County, Pa.
Hamm, William D., Box 749, Ardmore, Okla.
Hardin, E. Glenn, 318 E. Fifteenth St., Oklahoma City, Okla.
Harrington, Rollin B., The Empire Co., Bartlesville, Okla.
Harris, Richard C., Union Oil Company of Calif., Fort Collins, Colo.
Hazzard, Roy T., The California Co., Drawer 846, Colorado, Tex.
Heath, Francis E., 60 Front St., Waterville, Me.
Hedley, J. David, Waite Phillips Co., W. T. Waggoner Bldg., Fort Worth, Tex.
Hedrick, O. F., Thurber, Tex.
Henderson, Harold H., Ricker & Dodson, San Angelo, Tex.
Henry, Schuyler B., Drawer 846, The California Co., Colorado, Tex.
Hickey, Harold N., 104 S. Sumner, Creston, Iowa
Hillis, Donuil, 722 Common St., Lake Charles, La.
Hockman, James N., 528 Bob Waggoner Bldg., Wichita Falls, Tex.
Hoenshell, David T., 909 Twenty-second St., Bakersfield, Calif.
Hood, Harold H., 1582 Arcade Bldg., St. Louis, Mo.
Hoots, Harold W., U. S. Geol. Survey, Washington, D.C.
Hoover, William B., Box 1034, Humble Oil & Refining Co., Wichita Falls, Tex.
Hosterman, John F., Box 857, Shreveport, La.
Howe, A. Budrow, 507 White Bldg., Buffalo, N.Y.
Howendobler, John L., 1104 S. Lawton St., Tulsa, Okla.
Howeth, Irving K., Box 1865, Houston, Tex.
Hoyle, Charles R., 515 N. Oak St., Ponca City, Okla.
Hunt, Edwin H., 926 Patterson Bldg., Denver, Colo.
Hunt, Raymond S., Empire Gas & Fuel Co., Bartlesville, Okla.
Hunter, Paul B., 504 Central National Bank, San Angelo, Tex.
Hurndall, John P., Marland Oil Co., 200 Bush St., San Francisco, Calif.
Hutson, E. B., 615 Dewey Ave., Bartlesville, Okla.

Isenberger, N. P., 603 E. Ninth St., Winfield, Kan.
Israelsky, Merle C., Humble Oil & Refining Co., 903 Humble Bldg., Houston, Tex.

James, Wright E., General Petroleum Co., Higgins Bldg., Los Angeles, Calif.
Jay, Stanley E., Box 505, Pure Oil Co., San Angelo, Tex.
Jennings, Charles I., Mutual Oil Co., Patterson Bldg., Denver, Colo.
Johnson, Carl E., 841 Wilmington Ave., Salt Lake City, Utah

Johnson, J. Harlan, Box 343, Golden, Colo.
Johnson, Russell V., Johnson & Adair, Finch Bldg., Aberdeen, Wash.
Jones, Boone, Blackwell Oil & Gas Co., Blackwell, Okla.
Jones, Robert L., 320 E. Castro St., Norman, Okla.
Jones, Roy D., Box 169, Shawnee, Okla.
Just, Evan, Missouri Lead Co., Inc., Farmington, Mo.

Keenan, J. Kenneth, 709 Atlas Bldg., Tulsa, Okla.
Kelley, Donald, Box 1619, Marland Oil Co., Fort Worth, Tex.
Kerns, Floyd G., Standard Oil Co. of Venezuela, Maturin, Venezuela, S.A.
Keyes, Wilson, Drawer 846, Colorado, Tex.
Kidd, Robert L., Box 230, Madison, Kan.
Kilpatrick, O. H., 1115 West Twohig Ave., San Angelo, Tex.
King, Philip B., Dept. of Geology, University Station, Austin, Tex.
Kingsbury, Carl O., address unknown
Kinney, Harry D., Box 186, Easton, Pa.
Kittredge, M. B., The Pure Oil Co., Box 2007, Tulsa, Okla.
Knebel, G. Moses, Jr., Box 374, Mart, Tex.
Koch, Thomas W., 506 Petroleum Securities Bldg., Los Angeles, Calif.
Koschmann, A. H., 414 Monroe St., Stillwater, Okla.
Krecker, William H., Jr., 1428 Somerville Ave., Philadelphia, Pa.
Kroenlein, George A., Box 2065, Tulsa, Okla.
Krueger, Max L., Box 263, Tulsa, Okla.

Lane, Laura Lee, 1105-6 State National Bank Bldg., Houston, Tex.
Larkin, Harold P., U. S. Geol. Survey, Taft, Calif.
LaRue, James E., Humble Refining Co., Houston, Tex.
Laughlin, Rowland W., 1308 South Carthage, Tulsa, Okla.
Lavington, Charles S., 332 Forest Ave., Apartment 15, Palo Alto, Calif.
Lee, Huylar W., Engleman Hotel, Eastland, Tex.
Levings, W. S., Apartado 234, Venezuelan Gulf Oil Co., Maracaibo, Venezuela, S.A.
Lieb, Victor, 1402 Second National Bank Bldg., Houston, Tex.
Linker, Sophie, 970 Eastern Parkway, Brooklyn, N.Y.
Loskamp, Alvin P., Box 571, Fort Collins, Colo.
Luecke, Lester A., 900 Brook Ave., Wichita Falls, Tex.
Lynn, Robert H., Box 1073, % Phillips Petr. Co., Amarillo, Tex.
Lyster, Marvin E., South Bend, Tex.

MacDonell, James A., 312 S. Cole St., Lima, Ohio
Markley, Elmer A., Waite Phillips Co., Tulsa, Okla.
Marshall, Earl E., Box 71, Eldorado, Kan.
Mathes, Donald E., Box 135, Artesia, New Mexico

Matson, Martin, 710 Masonic Bldg., Bartlesville, Okla.
Mattson, Vernon L., S. A. E. Chapter House, Golden, Colo.
McArthur, Donald, Tropical Oil Co., Cartagena, Colombia, S.A.
McCabe, Roscoe E., State Mining Bureau, Santa Maria, Calif.
McClintock, Charles B., % Y.M.C.A., Bradford, Pa.
McClure, Joseph D., 1508 Washington St., Amarillo, Tex.
McCollough, Edward H., Box 2022, Tulsa, Okla.
McConnell, Philip C., Standard Oil Co., Production Dept., Bakersfield, Calif.
McCormack, John T., 5545 University Ave., Chicago, Ill.
McCullough, Russell L., 118 E. French Place, San Antonio, Tex.
McDonald, O. G., 601 Atlas Bldg., Tulsa, Okla.
McDonald, Worth W., Natural Gas & Fuel Co., El Dorado, Ark.
McDowell, Neil, Texas-Pacific Coal & Oil Co., Thurber, Tex.
McFarland, Paul W., Hamilton Hotel, Laredo, Tex.
McGaughey, John C., Box 343, Stamford, Tex.
McKague, Bruce C., Box 620, Roxana Petroleum Corp., San Angelo, Tex.
McKnight, C. R., Box 94, Shreveport, La.
McLaughlin, Homer C., Drawer B., Duncan, Okla.
McNeely, Robert, Tecumseh, Okla.
McVicker, Dwight S., 1980 C St., Lincoln, Neb.
Meland, Norman, Goldelline Oil Corp., 606 Braniff Bldg., Oklahoma City, Okla.
Merry, Edward T., Box 402, Coleman, Tex.
Mershon, Milton M., Box 1991, Tulsa, Okla.
Meyer, Arthur M., Box 720, Ardmore, Okla.
Meyers, Percy A., Box 1428, Wichita Falls, Tex.
Millar, John E., Jr., Mid-Continent Petroleum Corp., Geol. Dept., Tulsa, Okla.
Miller, Carroll C., Kellerton, Iowa.
Miller, Edward F., Box 1169, Denver, Colo.
Milner, Charles A., Jr., 413 N. Emporia, Wichita, Kan.
Mitchell, Robert C., Waite Phillips Co., Geol. Dept., Tulsa, Okla.
Mohr, Clifford L., Marland Oil Company of Texas, San Angelo, Tex.
Moncrief, E. C., Derby Oil Co., Wichita, Kan.
Morero, Joseph E., 1712 Grand Ave., San Pedro, Calif.
Morris, Walter W., Eagle Picher Lead Co., Oil and Gas Dept., Henryetta, Okla.
Morse, Paul F., Dept. of Geol., A. & M. College, Miss.
Moser, Gerald E., Box 379, Bartlesville, Okla.
Mower, Lowell K., Roxana Petroleum Corp., Box 1865, Houston, Tex.
Mulky, Francis P., 201 W. Fourteenth St., Oklahoma City, Okla.
Munson, Herbert E., % Dr. D. O. Munson, Pittsburg, Kan.
Murphy, Earle N., 824 S. Detroit St., Apartment 33, Tulsa, Okla.
Myers, Julian Q., 116 E. King St., Tulsa, Okla.

Nelson, Fred M., 543 First National Bank Bldg., Houston, Tex.
Nessly, Howard E., 927 Navarro St., San Antonio, Tex.
Newman, Thomas F., Midwest Exploration Co., Abilene, Tex.
Noble, Earl B., Union Oil Company of California, 514 Union Oil Bldg., Los Angeles, Calif.
Nolte, W. J., Marland Oil Company of Texas, 526 Bob Waggoner Bldg., Wichita Falls, Tex.
Nordman, O. E., Box 2044, Geol. Dept., Tulsa, Okla.

Oakes, M. C., 530 W. Symmes, Norman, Okla.
Obering, Ernest A., 1534 S. Newport St., Tulsa, Okla.
Oborne, Harry W., 413 First National Bank Building, Denver, Colo.
O'Brien, Shamus, Florence, Kan.
Oles, L. M., Prairie Oil & Gas Co., Box 263, Tulsa, Okla.
Oles, Paul S., Box 218, Eastland, Tex.
Osborne, Robert R., University Club, Tulsa, Okla.
Owen, Herman J., Ohio Oil Co., Findlay, Ohio
Oyster, Frank A., Box 392, Independence, Kan.

Packard, Sidney A., 627 W. Eighteenth St., Oklahoma City, Okla.
Palmer, Robert H., address unknown
Parks, Ernest K., 522 Standard Oil Bldg., San Francisco, Calif.
Paschal, Elisha A., 1011 Tradesman's National Bank Bldg., Oklahoma City, Okla.
Pease, Cecil C., 1261 Buchanan St., Topeka, Kan.
Perry, Samuel S., 601 S. Rampart St., Los Angeles, Calif.
Pettigrew, Virgil, Humble Oil & Refining Co., Box 1034, Wichita Falls, Tex.
Philbrick, Eugene P., 502 Patterson Bldg., Denver, Colo.
Pishney, Charles H., Carter Oil Co., Box 2045, Tulsa, Okla.
Polkinghorn, J. Wilbur, Garnett, Kan.
Pollak, Rudolf R., 1712 Second St., Bakersfield, Calif.
Pratt, Ernest S., Box 1263, Marland Refining Co., Ponca City, Okla.
Price, Earl M., Associated Oil Co., Oil Center, Calif.
Putnam, Laurence G., 912 Ninth St., Brownsville, Tex.

Quiett, Roy C., Box 413, Ponca City, Okla.

Ralston, Wallace, 2309 W. Platte St., Colorado Springs, Colo.
Rathwell, Harold B., 4921 Cimarron St., Los Angeles, Calif.
Reed, Lyman C., Rio Bravo Oil Co., 320 Southern Pacific Bldg., Houston, Tex.
Reed, Warren B., Morgan City, La.
Reiter, Wilhelm A., Box 856, Mexia, Tex.
Reynolds, Karl W., Box 322, Wynnewood, Okla.

Reynolds, Robert E., 318 Spaulding St., San Angelo, Tex.
Richards, A. Howard, Geol. Dept., Marland Oil Co., Ponca City, Okla.
Ridgeway, Bertrand S., Box 392, Independence, Kan.
Ridings, Lowell J., Apartado 94, Tampico, Mex.
Rife, Byron, 311 N. Second St., Independence, Kan.
Robbins, C. C., 1710 Union Bank Bldg., Pittsburgh, Pa.
Roberts, Dwight C., 2000 W. Twelfth St., Los Angeles, Calif.
Roberts, Louis C., Jr., Waite-Phillips Co., 2019 W. T. Waggoner's Bldg., Fort Worth, Tex.
Robertson, Parker A., Apartado 106, Tampico, Mexico
Robinson, B. F., 1736 E. Fourteenth St., Tulsa, Okla.
Rogatz, Henry, 822 Thirteenth St., Golden, Colo.
Roop, Charles W., Drawer "L," Bartlesville, Okla.
Roth, Ernest R., 6240 Saint Marie St., Pittsburgh, Pa.
Rubel, Albert C., 3766 Magnolia Ave., Long Beach, Calif.
Russell, J. R., Room 1130, Standard Oil Bldg., San Francisco, Calif.
Rutledge, Richard B., Box 815, Winfield, Kan.
Ryan, Reginald G., 1217 Bonnie Brae, Houston, Tex.
Ryniker, Charles, Box 2044, Tulsa, Okla.

Say, Stanley R., Pan-American Explor. Co., 120 Broadway, New York, N.Y.
Schlosser, Paul A., Phillips Petroleum Co., San Angelo, Tex.
Schmidt, Karl A., Box 308, Tidal Oil Co., Abilene, Tex.
Schmittou, Maurice B., Apartado 162, Tampico, Mexico
Schneider, G. W., Box 96, Shreveport, La.
Schnurr, Cornelius, 105 E. College Ave., San Angelo, Tex.
Schoeneck, Philip S., Geol. Dept., Atlantic Oil Prod. Co., Dallas, Tex.
Schwab, Philip A., 415 Mason Bldg., Houston, Tex.
Schwarz, Melbert E., 318 Southern Pacific Bldg., Houston, Tex.
Seitz, J. R., Billings, Okla.
Severson, George A., Maturin, Estado de Monagas, Venezeula, S A.
Shakley, Ed. G., 435 Reynolds Ave., Kittanning, Pa.
Shoults, Carl S., Box 78, Toyah, Tex.
Sidwell, Carroll V., Huasteca Petroleum Co., Geol. Dept., Apartado 94, Tampico, Mexico
Simpson, Earl J., Roxana Petroleum Corp., Houston, Tex.
Skirvin, Orren W., Box 282, American Oil & Refining Co., Ada, Okla.
Smiley, H. F., Marland Oil Company of Texas, San Angelo, Tex.
Smith, Erwin W., 312 West Building, Houston, Tex.
Smith, Merritt B., Tropical Oil Co., Apartado 170, Cartagena, Barranca-Bermeja, Colombia, S.A.
Smoots, John P., 407 Jordan St., Shreveport, La.
Solliday, A. L. Dixie Oil Co., 332 Harvey-Snider Bldg., Whichita Falls, Tex.

Sorensen, Alfred H., Ord, Neb.
Spangler, Grant W., Box 826, Winfield, Kan.
Spice, William H., Jr., 706 Travis Bldg., San Antonio, Tex.
Splane, Howard S., Devonian Oil Co., Box 1441, Tulsa, Okla.
Sprague, William B., Drawer C, Houston, Tex.
Spriggs, Herbert S., Tropical Oil Co., Apartado 170, Cartagena, Colombia, S.A.
Staggs, Olan B., Atlantic Oil Producing Co., Apartado 223 Maracaibo, Venezuela, S.A.
Stanley, M. Wood, 4225 Hall St., Dallas, Tex.
Stastny, Herman R., T. P. Coal & Oil Co., Thurber, Tex.
Stein, Ira H., Cherokee, Okla.
Steiner, Dr. George, 319 Cotton Exchange Bldg., Houston, Tex.
Stephano, Constantine S., 1014–16 Walnut St., Philadelphia, Pa.
Stewart, Charles H., 510 W. Fifth St., Cisco, Tex.
Stilley, Earl M., Floral Apartments C. Wichita Falls, Tex.
Stipp, Thomas F., Associated Oil Co., Room 637, 79 New Montgomery St., San Francisco, Calif.
Swiger, Rual B., Box 267, Coleman, Tex.

Tappolet, Werner, Box 1109, Geol. Dept., Dallas, Tex.
Taylor, Cyril B., Box 826, Winfield, Kan.
Taylor, Thomas G., Empire Refineries Inc., Tulsa, Okla.
Teas, Paul C., 1014 W. T. Waggoner Bldg., % Deep Rock Oil Co., Fort Worth, Tex.
Teets, D. Dee, Jr., Richmond Apartments No. 3, 105 Bradford St., Charleston, W.Va.
Tharp, Paul A., 320 E. Eleventh St., Winfield, Kan.
Thompson, B. E., Box 737, Fort Worth, Tex.
Thompson, T. C., address unknown
Thornburgh, H. R., Box 1865, Houston, Tex.
Tillotson, Harold H., Latham, Kan.
Toler, Henry N., 249 Natural History Bldg., University of Illinois, Urbana, Ill.
Torrey, Paul D., 3904 Forbes St., Oakland Station, Pittsburgh, Pa.
Trainer, David W., Jr., McGraw Hall, Cornell University, Ithaca, N.Y.
Tweedy, Joseph L., Knickerbocker, Tex.
Tygrett, Howard V. Atlantic Oil Prod. Co., Magnolia Bldg., Dallas, Tex.
Tyson, Alfred K., Maysfield, Tex.

Upham, Harry R., address unknown

Valerius, Claude N., Wilcox Bldg., Tulsa, Okla.
Van Dall, John E., Box 1612, Holdenville, Okla.
Van Weelden, Aric, Roxana Petroleum Corp., Dallas Athletic Club Bldg., Dallas, Tex.

Van Zant, James H., 1024 W. Fifth St., Oklahoma City, Okla.
Vernon, Jess, Box 336, Okmulgee, Okla.
Vertrees, Charles D., 1621 West Beauregard St., San Angelo, Tex.

Waldo, Kenneth C., 952 Colbert Ave., Oil City, Pa.
Waring, John D., Jr., city engineer, Comanche, Tex.
Waterfall, Louis N., 1569 Spruce St., Berkeley, Calif.
Waters, James A., The Sun Co., Box 1109, Dallas, Tex.
Watkins, Walter G., 32 Second St., Rankin, Pa.
Watkins, William A., Edificio Banco Boston 713, Buenos Aires, Argentina, S.A.
Watson, Cresap P., 65 Broadway, Amerada Corp., New York City
Watson, Joseph D., 2543 E. Eleventh St., Tulsa, Okla.
Weaver, Donald K., 141 Brookdale Ave., Fullerton, Calif.
Webster, Hugh B., Standard Oil Co., Standard Oil Bldg., San Francisco, Calif.
Weeks, Herbert J., Sun Oil Co., Box 1109, Dallas, Tex.
Weinzierl, John F., McLoud, Okla.
Weisbord, Norman E., 227 Haven Ave., New York City
Wendlandt, Edward A., 908 Humble Bldg., Houston, Tex.
West, Joe W., Venezuelan Gulf Oil Co., Apartado 40, Barcelona, Venezuela, S.A.
Whealton, Rowland G., Box 3348, Taft, Calif.
Wheeler, Carlton W., Box 267, Coleman, Tex.
Wheeler, Holmes C., Healdton Oil & Gas Co., Enid, Okla.
Whitcomb, Bruce, % Ricker & Dodson, San Angelo, Tex.
White, Maynard P., International Petroleum Co., Tampico, Mexico
White, Stanley B., Box 938, Cushing, Okla.
Whitney, Paul A., Box 1162, Tulsa, Okla.
Whitwell, Elvis B., 216 East Tonhawa St., Norman, Okla.
Whitworth, Virgil L., Simms Oil Co., Magnolia Bldg., Dallas, Tex.
Wiest, Frank C., Crusader Pipe Line Co., Shreveport, La.
Williams, Francis S., 704 Shell Bldg., Silurian Oil Co., St. Louis, Mo.
Williamson, Thomas Scott, Marland Refining Co. Geol. Dept., Ponca City, Okla.
Wilshire, L. M., Box 225, Shawnee, Okla.
Wilson, John H., 650 Pennsylvania Street, Denver, Colo.
Wilson, Joseph M., Simms Oil Co., 10th Floor, Magnolia Bldg., Dallas, Tex.
Wilson, Leslie Edwin, U. S. Bureau of Mines, Seattle, Wash.
Witherspoon, Gavin, Jr., Standard Oil Bldg., Box 1200, Bakersfield, Calif.
Wolf, Albert G., Texas Gulf Sulphur Co., Gulf, Matagorda County, Tex.
Woods, Earl H., The Texas Co., Wichita Falls, Tex.
Wood, Fred E., Midwest Refining Co., Casper, Wyo.
Word, Ernest B., Box 518, Covington, Okla.
Wosk, L. David, 1231 South Boulder St., Tulsa, Okla.
Wright, Andrew C., 1032 Athletic Club Bldg., Dallas, Tex.

Wuensch, C. E., % Cia Real Del Monte, Pachuca, Hidalgo, Mexico
Wylie, James R., Jr., 424 Whitney Ave., Wilkinsburg, Pa.
Wyman, Everett A., Amerada Corp., Box 2022, Tulsa, Okla.

Zaba, Joseph, Westlake, La.
Zavoico, Basil B., 342 Masonic Bldg., Enid, Okla.
Zoller, Henry E., Box 278, Braman, Okla.
Zorichak, Joseph J., Midwest Refining Co., Grass Creek, Wyo.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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Memorial

Henry L. Hamilton

Henry L. Hamilton died in San Antonio on May 29, 1925, following a major operation for stomach trouble.

He was born September 8, 1882, on a farm near Modesto, California. He graduated from Palo Alto High School in 1900 and from the department of geology and mining of Stanford University in 1904. During his high-school and university days he made an enviable record as an excellent student and as an athlete, his specialty in athletics being the sprints.

Following his graduation he spent three years in mining work in California and Mexico, being compelled to resign from the position of assistant manager of a large mine to return to the States on account of illness resulting from unfavorable climatic conditions. In order to recover his health he spent a few years farming.

In 1913 he began his career in the oil fields with the Montebello Oil Company at Fillmore, California. He learned the work of oil development and production in the field and advanced to the position of superintendent in 1915. In 1916 he resigned and left California for consulting work in the Tennessee phosphate fields, after which he opened an office in Houston, Texas, as a consulting engineer. In 1917 he joined the force of Oil Issues Company, in which the writer was interested, remaining with that concern in charge of its southern work until its consolidation with the Mutual Oil Company in 1923.

He then moved his headquarters to San Antonio and acquired acreage in the Somerset field, which he later successfully developed. He also acquired producing acreage in Callahan County, Texas, and at the time of his death was, without doubt, destined for a successful career as an independent producer.

Having been closely associated with him all his life, the writer probably knew him better than did any other man. He was of a lovable disposition and of unquestioned integrity, and he had amazing will-power. His life, short as it was, has left an undying impression upon the minds and hearts of those who knew him.

He is survived by a widow and a thirteen-year-old son, Lloyd.

W. R. HAMILTON

HENRY L. HAMILTON

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

M. L. TALIAFERRO, who has for sometimes been connected with Ventura Consolidated Oil Fields, Los Angeles, California, has accepted an appointment as associate professor of geology in the University of California.

MALVIN G. HOFFMAN, formerly with the Carter Oil Company, is now doing consulting work. His new address is 1619 South Newport Street, Tulsa, Oklahoma.

FREDERIC H. LAHEE, chief geologist of the Sun Oil Company, sailed from Houston on February 22 on a business trip to Venezuela. He was to be absent from the United States about five weeks.

F. X. BOSTICK, for the past several years paleontologist with the Standard Oil Company of Louisiana at Shreveport, accepted a position with the geological staff of the Southern Crude Oil Purchasing Company, Slattery Building, Shreveport, effective February 15.

CARL H. DANE and PAUL E. TORREY, of the U. S. Geological Survey, Washington, D.C., completed the field work, February 1, of a report on the Cretaceous of southwestern Arkansas, and after collecting additional material in Shreveport, Louisiana, returned to Washington for completion of the report.

SIDNEY POWERS, chief geologist for the Amerada Petroleum Corporation at Tulsa, Oklahoma, visited the Shreveport, Louisiana, office of the company in February.

V. V. WAITE, who has a consulting office at 906 Insurance Building, Dallas, Texas, was in Shreveport, Louisiana, several days in February, on a business trip.

F. F. HINTZE, consulting geologist, 400 California Building, Denver, Colorado, visited Shreveport, Louisiana, in behalf of clients last February, and attended one of the regular weekly luncheons of the Shreveport Geological Society at the Washington Hotel.

HARRY H. NOWLAN is now with the Galer Oil Company, 611–615 Clinton Building, Tulsa, Oklahoma, as vice-president and geologist.

CHARLES E. STRAUB, of Wichita, Kansas, who has been doing consulting work, is now representing the Dixie Oil Company, Inc., in Kansas and part of north-central Oklahoma, with offices at 515 W-K-H Building.

At a recent meeting of the ARDMORE GEOLOGICAL SOCIETY the following officers were elected for the year 1926: GEORGE E. BURTON, president; S. H. WOODS, vice-president; R. A. BIRK, secretary and treasurer.

KENNETH B. NOWELS, who has been with the United States Bureau of Mines at Dallas, Texas, has been transferred to Laramie, Wyoming, where he will be engineer in charge of the Bureau of Mines, relieving D. B. Dow, who has been sent to Bartlesville, Oklahoma.

H. V. HOWE, head of the department of geology at Louisiana State University, Baton Rouge, Louisiana, has resumed his university extension work in graduate geology at Shreveport, Louisiana. He is delivering a course of monthly lectures from January through June on the general subject of "The Paleontological Correlation of the Claiborne Formations," based largely on microscopic study of core samples from the Urania, LaSalle Parish, field, furnished by the Louisiana Oil Refining Corporation. The lectures are given under the auspices of the Shreveport Geological Society.

H. W. BELL, supervisor of the minerals division of the state department of conservation, Shreveport, Louisiana, is the author of *Bulletin No. 12* of that department, entitled, "The Monroe Gas Field." The chapter on geology is contributed by W. C. SPOONER.

H. K. SHEARER, geologist with the Standard Oil Company of Louisiana, Shreveport, spent part of his vacation the early part of the year in Dallas, Texas.

JOHN B. KERR, 601 Balboa Building, San Francisco, California, visited friends at Shreveport, Louisiana, last January, while en route to Tennessee on business.

The completion of the Shafer well by the MIDWEST EXPLORATION COMPANY on the Cane Creek anticline, near the town of Moab, Utah, flowing initially 350 barrels of 40-gravity oil is a very interesting development opening up new territory in Utah. The discovery is doubtless of special interest to H. W. C. PROMMEL, now at Wichita Falls, Texas, who, working with Fisher and Lowry of Denver, mapped this structure in 1920. A paper by Prommel in Vol. 7, pages 384–99, 1923, describes this region.

REESE L. HAYES is now president of the Roamer Oil Company, with headquarters at 256 Harvey-Snider Building, Wichita Falls, Texas.

R. E. BENDING is chief geologist for the Manhattan Oil Company, with headquarters in El Dorado, Kansas.

C. D. STEPHENSON, chief geologist of the Wrightsman Petroleum Company, will spend a leave of absence at Columbia University, where he will engage in graduate studies.

A. E. STANDER, of the Texas Company, has been transferred from Tulsa to Wichita, Kansas, where he will have charge of their geological work.

A. W. LAUER has been appointed division geologist of the Texas Company, at Tulsa.

E. W. SCUDDER, of the Gypsy Oil Company, has been transferred from Wichita to Denver, changing places with ROY H. HALL, who will move to Wichita.

The Austin section of the SOUTHWESTERN GEOLOGICAL SOCIETY meets regularly on the first Friday of each month at 8:00 P.M., Room 315, Main Building, University of Texas. Visiting geologists are invited to all meetings of the society. At the meeting on February 5 a discussion on "Cretaceous Shore Lines" was led by Professor CHARLES SCHUCHERT.

W. C. SPOONER, consulting geologist, Ardis Building, Shreveport, Louisiana, went to Mexico and Central America early in December for two months' work in the Tehuantepec region.

J. M. WILSON, in charge of geological work for the Simms Oil Company at Dallas, Texas, visited his friends in Shreveport, Louisiana, last December. Mr. Wilson has been doing considerable detailed field work in the Laredo, Texas, district.

S. C. STATHERS, chief geologist for the Standard Oil Company at Shreveport, Louisiana, visited friends and relatives in Philadelphia and West Virginia during the Christmas holidays.

THE U. S. GEOLOGICAL SURVEY local office, which was opened last summer in the City Bank Building, Shreveport, Louisiana, has been discontinued because of the relatively small amount of government land leased in this district.

HAROLD R. SHIDEL, formerly of Wichita, Kansas, is located in Shreveport, Louisiana, interested in O. C. S. Manufacturing Company equipment.

L. W. PETRIE, geologist with the Roxana Petroleum Corporation, has been transferred from the Shreveport, Louisiana, office of the company, to Dallas, Texas, headquarters.

GEORGE SCHNEIDER is in the geological department of the Texas Company, working out of the Shreveport, Louisiana, office.

WORTH W. MCDONALD has resigned his position as geologist with the Louisiana Oil Refining Corporation at Shreveport, Louisiana, to become geologist for the Natural Gas and Fuel Corporation with headquarters at El Dorado, Arkansas, effective January 1.

LESLIE S. HARLOWE, recently geologist with the Southern Crude Oil Purchasing Company, on January 1 accepted a position in the producing department of the Louisiana Oil Refining Corporation, Shreveport, Louisiana.

CHARLES I. JENNINGS, geologist for the Continental Oil Company, with field headquarters at Fort Worth, Texas, has been doing considerable work in the Shreveport, Louisiana, territory.

RALPH E. DAVIS, engineer, 1710 Union Bank Building, Pittsburgh, Pennsylvania, was in Shreveport, Louisiana, in December and January, engaged in making a gas survey of Louisiana, with particular reference to the Monroe gas field.

H. W. BELL, supervisor of the minerals division of the Louisiana State Conservation department at Shreveport, announces the following change in the

office of geological engineer. M. W. GRIMM, who resigned from the division January 1 to take charge of geological work for the Tidal Oil Company in the Shreveport district, is succeeded by WITHERS CLAY.

At the meeting of the ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS on Thursday, December 17, the following officers were elected for the year 1926: president, CHARLES M. RATH; vice-presidents, ALEXANDER W. MCCOY and E. RUSSELL LLOYD; secretary, ROY HOLLOMAN. Regular luncheon meetings are held at the Adams Hotel, Denver, on the first and third Thursdays of each month.

MAX W. BALL spent two weeks in December visiting the oil fields of eastern New Mexico, west Texas, and Marion County, Texas. CLARE COFFIN, chief geologist for the Midwest Refining company, accompanied Mr. Ball to New Mexico and west Texas.

L. R. VAN BURGH, valuation engineer of the Income Tax Unit, Internal Revenue Bureau, has been transferred from Washington to Denver. The Rocky Mountain region is very glad to have him back, together with Mrs. Van Burgh, and their two children.

CARROLL H. WEGEMANN underwent an operation for gall stones at St. Josephs Hospital, Denver, on December 12. He is getting along nicely and will return soon to his duties as chief geologist of the Pan American Exploration Company, with headquarters at 120 Broadway, New York.

THE ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS, on December 4, entertained its members and their friends at the home of C. A. FISHER, 314 Franklin Street, Denver. The hosts were MAX W. BALL, C. A. FISHER, THOMAS S. HARRISON, DEAN E. WINCHESTER, JOHN WELLINGTON FINCH, and HAROLD W. LOWRIE.

J. P. SCHUMACHER, who returned last summer from Europe with two torsion balance instruments, is engaged in consulting work. His headquarters are 900 Ruth Avenue, Houston Texas.

DONALD F. MACDONALD is away from Casper, on leave of absence, during the winter season, to do mineral land valuation work for New York banking interests. He has recently been in Alabama and on the Mexican border, having had his work on certain cement areas in western and central New York cut short by inclement weather. His forwarding address is 16 Eastover Court, Louisville, Kentucky.

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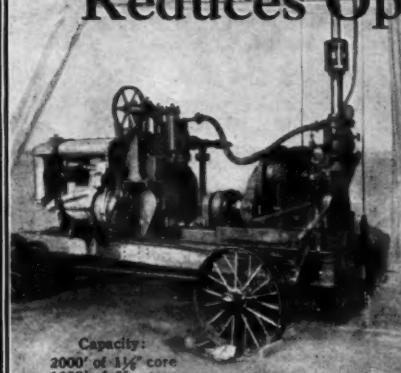

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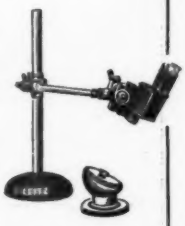

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